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AND
TENNESSEE VALLEY AUTHORITY

Health and Safety Department

Malaria Control ON IMPOUNDED WATER

1947

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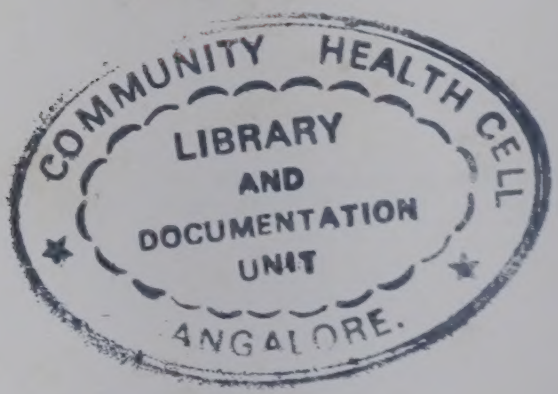

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FOREWORD

The impoundage of flowing streams profoundly alters the biology of the affected waters. One of the changes may be a vast increase in the potential for anopheline mosquito production unless appropriate control works and procedures are planned, designed, and operated. The choice is, therefore, between the probability of a disastrous "man-made" increase in transmission of malaria or a successful resolution of the continuing conflict between adverse biological pressures and control practices.

There is no ready-made formula which is applicable under all circumstances to all impoundments, for variations in ecological conditions and the primary purposes of water control are practically infinite. Hence, plans for malaria control on impounded water, though following basic principles, must be specifically adapted in method to each particular project by the selection of specifically applicable alternatives as delineated by local ecology and objectives. This publication records a comprehensive body of experience in the design and operation of programs of malaria prevention on impounded water and, while certain principles here presented seem to have been established with at least a measure of finality, this manual is no final word on the subject. On the contrary, it is essentially a report of progress submitted for such value as it may have to others confronted by similar tasks.

The program of regional development undertaken in 1933 by the Tennessee Valley Authority, based primarily on water control, afforded a unique opportunity for the study and application of alternative malaria control measures under circumstances involving more than 10,000 miles of reservoir shore line in a region of widely varying topography. The experience of the United States Public Health Service has, of course, been acquired over a much broader geographic and ecologic range than has that of the Authority. Thus, there is here joined the experience gained by both intensive work on a regional basis and extensive operations on a national scale. The result of this pooling of knowledge, experience and research effort, together with consultation from other competent authorities, has been a sustained increase in the efficiency and economy of control practices as applied in the work of the TVA.

It is fully recognized that present information is incomplete and that there is urgent need for competent inquiry into many questions, for the knowledge of tomorrow may well result in substantial change of today's concept of control.

E. L. Bishop, M.D.
Director of Health, Tennessee Valley Authority.

PREFACE

The purpose of this manual is to present the basic principles and the modern practices of malaria control on impounded water. It is arranged so as to provide a ready reference for engineers, medical officers, and others concerned with malaria control measures on such impoundments. In considering the various phases of malaria control such as its epidemiological, engineering, and biological aspects, emphasis has been placed on their practical application to the problem as a whole.

In the preparation of this manual, various sources of information and experience have been used to present methods appropriate in the planning and application of malaria control measures on impounded water in the United States and especially in the Southeastern States. Many of the basic principles and practices discussed are also applicable to impounded waters in other regions of the world.

The manual includes a brief discussion of malaria, its history and relationship to reservoirs, and the responsibility of those impounding water (ch. I). The basic elements of planning malaria control programs for both proposed and existing impoundages, including analysis of the problem, selection of control measures, integration with other reservoir interests and operations, and the necessary organization and personnel, are considered in chapter II.

The primary antilarval measures and their application in the control of malaria mosquitoes are discussed in some detail in the chapters on reservoir preparation (ch. III), permanent marginal measures (ch. IV), water level management (ch. V), shore-line maintenance (ch. VI), and larviciding (ch. VII). Supplementary control measures, such as mosquito-proofing and house-spraying are considered in chapters VIII and IX. The facilities, field operations, and reports necessary in carrying out a malaria control program are mentioned briefly in chapter X.

A general discussion of anopheline mosquitoes, their identification and biology, and entomological appraisal, with emphasis on their practical application in malaria control, is given in chapter XI. The epidemiology of malaria and methods of conducting malaria surveys are considered in chapter XII on malariology.

The relationship of plants to mosquito propagation and to such antilarval measures as reservoir preparation, water level management, shore-line maintenance, and the application of larvicides is discussed in chapter XIII. The relationships of the above antilarval measures, including shore-line improvement, to wildlife conservation are pointed out in chapter XIV. Methods of training personnel

and maintaining proper public relationships are given in chapter XV.

Because the problems and methods of malaria control on small impoundages differ considerably from those of larger reservoirs, a special chapter (ch. XVI) has been included at the end of the manual to consider the application and adaptation of the measures previously discussed to small reservoirs.

An appendix includes abstracts of various State regulations pertaining to malaria control on impounded water, design data, specifications for materials and equipment, malaria mosquitoes of the world, technique for making blood film slides, and other detailed information related to malaria control.

This manual was prepared jointly by members of the Health and Safety Department of the Tennessee Valley Authority and the malaria control headquarters (Atlanta) of the United States Public Health Service. Principal contributors were:

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Officials of State health departments, members of the staff of the Corps of Engineers of the War Department, the Fish and Wildlife Service, and the Bureau of Reclamation of the Department of the Interior, the Department of Agriculture, and numerous individuals, contributed their knowledge and experience to the preparation of this manual. Since their number precludes separate mention, the authors welcome this opportunity to express thanks for the cooperation and assistance of all to whom they turned for criticism and review.

Preparation of the manual was accomplished under the general guidance of Dr. E. L. Bishop, Director, Health and Safety Department, Tennessee Valley Authority, and Mr. M. D. Hollis, Sanitary Engineer Director, in charge of malaria control for the United States Public Health Service. The organization and editorial treatment was under the direction of Mr. C. I. Mansur.

I. MALARIA AND ITS RELATION TO IMPOUNDED WATER

DISCOVERY OF THE NATURE OF MALARIA

The occurrence of "chills and fever" during warm seasons of the year in association with ponded water has been recognized and recorded for more than 2,000 years. The Greek physician, Hippocrates, described the recurrent character of such fevers, identifying them almost unmistakably as being due to malaria parasitism. Contemporary documents of ancient civilizations of the Mediterranean area leave no doubt that there was early and general recognition of the unhealthiness of living near ponds, marshes, and swamps. There are many evidences in Italy of ancient attempts to drain such collections of water. Later, laws were enacted which served in effect to prevent impoundage of water or to depopulate areas near impounded water, an example being the Italian Agrarian Laws of 1810.

The word "malaria" was used about the year 1827 by John MacCullough, a London physician, to describe these febrile illnesses associated with swampy places. Previously the term had been used (as its etymology implies) to denote the emanations from marshes and swamps, exposure to which was supposed to cause these illnesses. In 1880 Laveran, a French Army surgeon, first described microscopic organisms in the blood of malaria patients and associated them with the illness. Ross, an English Army surgeon, in 1897 proved that analogous parasites in birds were transmitted by mosquitoes and suggested that the parasites in humans were transmitted similarly. Subsequently, the role of *Anopheles* mosquitoes in the epidemiology of human malaria was established by Italian scientists under the leadership of Grassi in about 1898. By 1900 the basic principles of the current concepts of malaria and its control had been established. Subsequent research has served largely to refine this fundamental knowledge.

The word "malaria" as originally used by MacCullough has been retained even though we now know that malaria includes at least four distinct human diseases produced by infection with four different species of the genus *Plasmodium: P. vivax, P. falciparum, P. malariae,* and *P. ovale.* While the clinical expression of these infections and their epidemiology vary considerably, they have some common denominators: they all produce recurring fevers, anemia,

and enlargement of the spleen; all react favorably to treatment with quinine or atabrine; and their causative agents are all transmitted by anopheline mosquitoes.

OCCURRENCE AND DISTRIBUTION OF MALARIA

Malaria occurs in almost every part of the world where physiographic factors tend to produce and to maintain aquatic environments favorable to anopheline mosquito propagation, and where the agricultural economy of the region is associated with a relatively low standard of living. Figure 1 shows where malaria exists as an actual or potential problem in the various regions of the world. In those areas where it exists in an endemic state, it is usually one of the most important diseases from a public health and economic standpoint with which local health agencies have to contend.

The basic physical requirements for the occurrence of malaria are water and an average atmospheric temperature higher than 68° F. for at least 2 months of the year. By and large, in the temperate and subtropical zones the water must be quiet water such as that which occurs in marshes, swamps, ponds, and lakes; but even temporary collections of water, such as those which occur in the hoofprints of cattle or in depressions made by wheels, may serve as breeding places for some anopheline species. Some tropical species

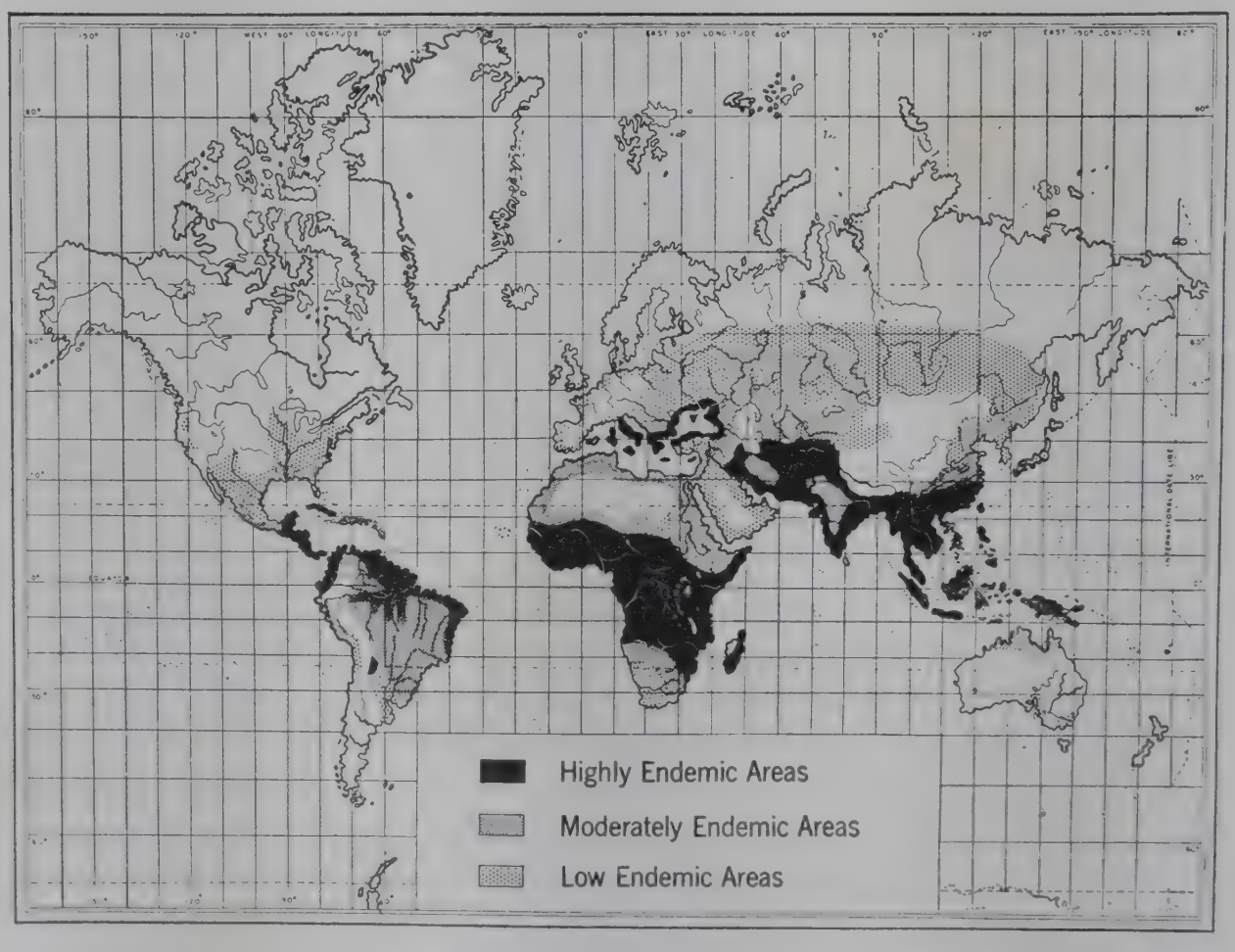

FIGURE 1.—Geographic distribution of malaria (1940-1945).

require, or at least prefer, water with perceptible motion. In the United States, the malaria mosquitoes generally prefer fresh, quiet water for propagation. Thus, natural breeding places are found associated with lime-sink (karst) topography; with conditions which block the outlet of streams, thus producing swamps and marshes; and with old streams of low gradient whose meandering courses leave "ox-bows" and "cut-offs", and which are subject to overflow near the onset of summer. The first-named situations are found on both sides of the southern end of the Appalachian Plateau, across southern Georgia and Alabama, and in the Tennessee Valley. Typical riparian breeding places are associated with the Mississippi River and its main tributaries.

MALARIA VECTORS

Entomological studies have revealed that there are over 200 species of anopheline mosquitoes throughout the world, all of which are probably capable of transmitting malaria under laboratory conditions. Fortunately, there are only about 10 or 12 really potent malaria vectors. Biting habits and other limiting biological factors apparently render the majority of the *Anopheles* harmless. In order that an anopheline mosquito be a "good vector" it must be present in sufficient numbers to transmit the disease, and it must have an instinct for the repeated taking of human blood meals. Of the 13 known anopheline species in the United States, only 2, *A. quadrimaculatus* and *A. freeborni,* are known to be of epidemiological significance.

In general, significant *A. quadrimaculatus* densities exist east of the Mississippi River from the Great Lakes to the Gulf of Mexico, and for some distance west of the Mississippi, being most prevalent in the Mississippi River Valley and the Southern States. The distribution of *A. freeborni* is associated principally with irrigated lands of the Southwest and the river valleys of California.

MALARIA IN THE UNITED STATES

Malaria was introduced into the United States in colonial days by emigrants from highly endemic centers in the Old World. The importation of negro slaves for a period of 200 years constantly replenished the supply of malaria carriers. Water was used for transportation and for power to a greater extent than prevails today. and settlements, as a matter of course, developed along streams. Colonial housing offered little or no impediment to the entrance of mosquitoes, and contemporary documents indicate that the inhabitants were constantly plagued by mosquito bites. The result was that malaria moved westward with the settlement of the country.

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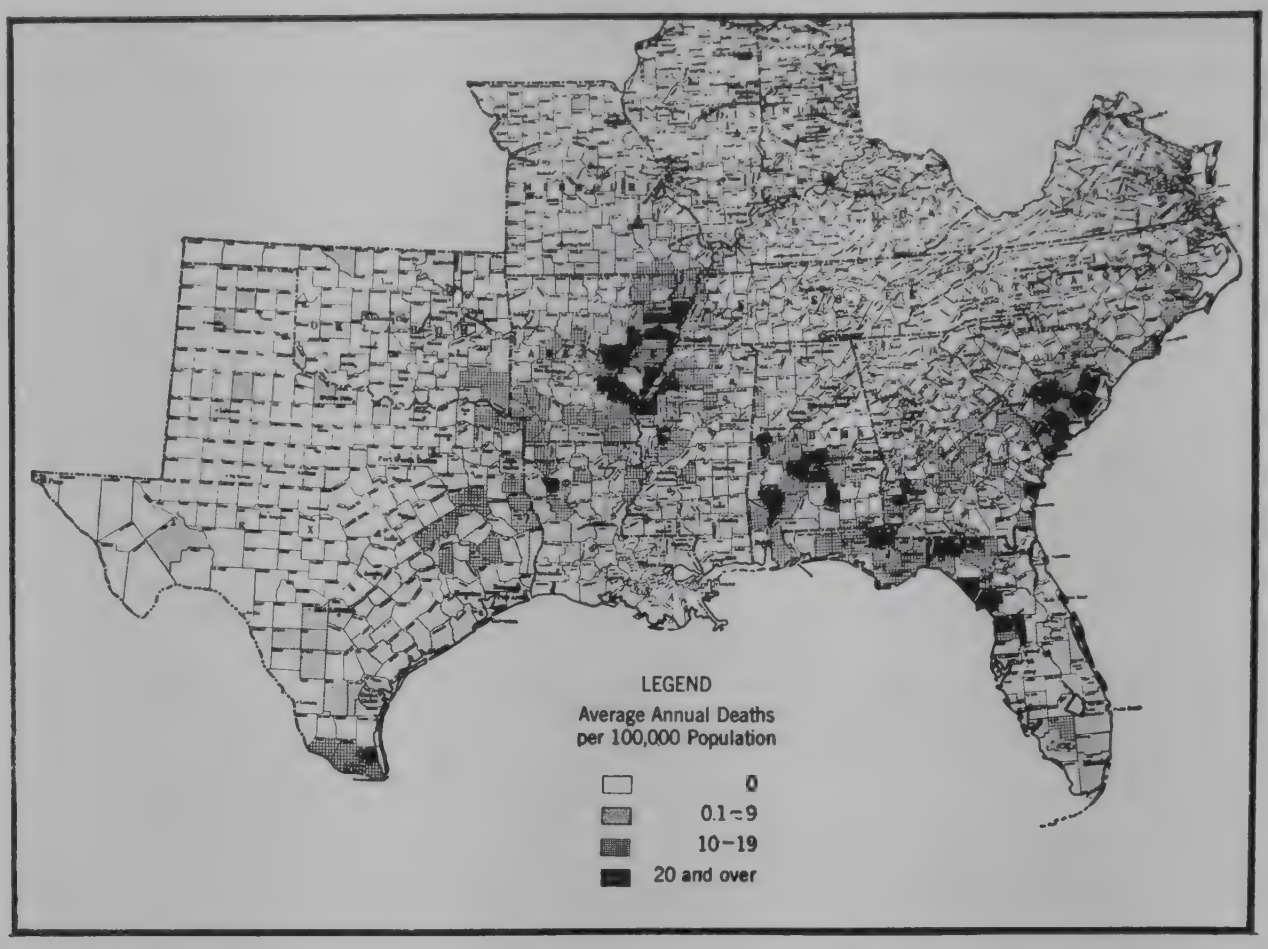

FIGURE 2.—Average annual malaria deaths in the southeastern United States (1938-42). (Compiled from State health department records.)

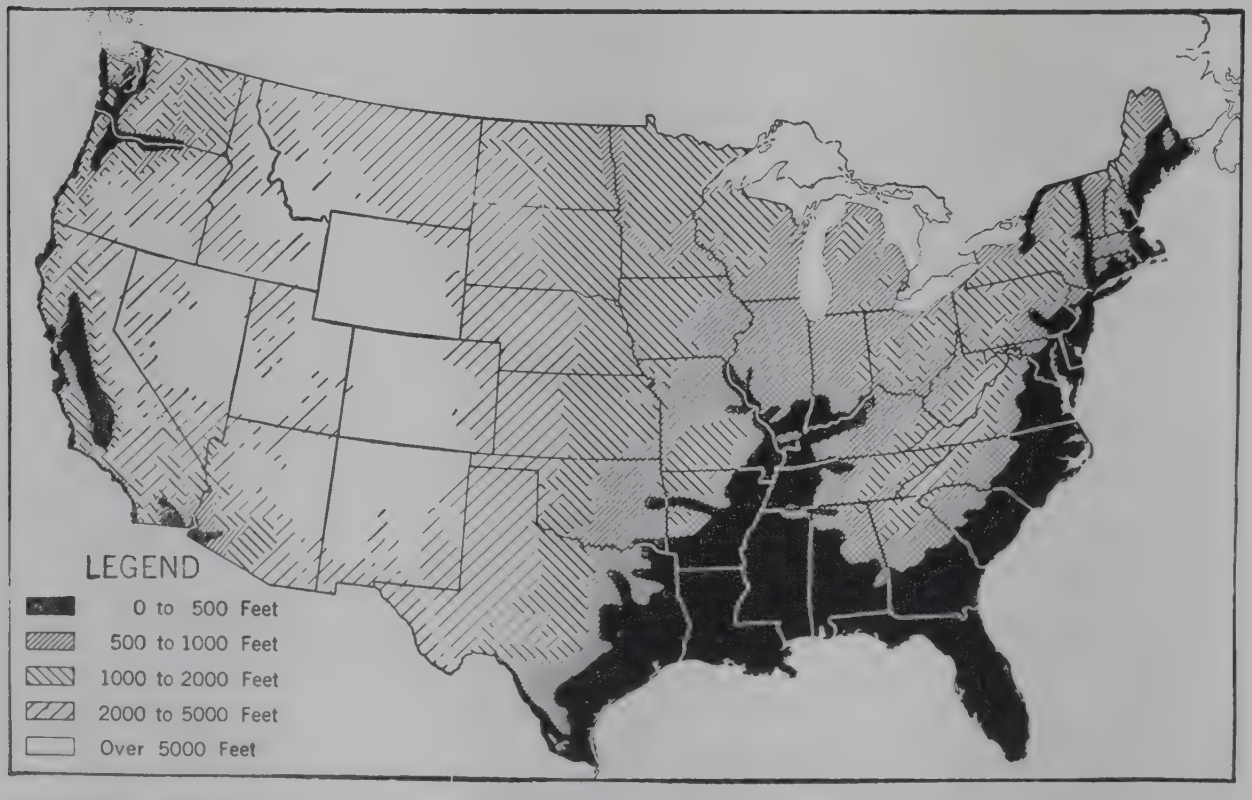

FIGURE 3.—Topographic map of United States showing valleys and coastal plains where, with proper climatic conditions, anopheline production potentials are usually greatest.

Early in the eighteenth century malaria was widespread throughout the coastal plain south of the Chesapeake Bay. While no highly endemic areas appear to have been established north of the Ohio River, many epidemics did occur, and a small number of endemic foci were established. Malaria did not commence to retreat to the Southeastern States until about 1850. The decrease in the other parts of the country was brought about in part by the rising price of agricultural products, due to the opening of eastern markets by railroads, and a consequent use of drainage for agricultural purposes. This, with the early industrialization of the northeastern part of the country, raised the economic level of the general population to a point which resulted in better housing. Moreover, the advent of steam power gradually reduced the number of small impoundments, which further reduced the number of breeding places of mosquitoes.

In this country anophelism with malaria is mainly found in rural areas of valleys, coastal plains, and piedmont sections of the Southeastern States, and where housing and other living conditions are poor (figs. 2 and 3). There is also extensive occurrence of anophelism without malaria in places where malaria existed formerly. This circumstance is inherently dangerous: given the presence of malaria carriers and nonimmunes accessible to anopheline mosquitoes, malaria can and will recur in localities where it has not been present in the memory of living man. As a matter of fact, outbreaks have occurred in such situations within the last 10 years. An outbreak of malaria occurred at Camden, N. J., as a result of prolific breeding of *A. quadrimaculatus* following the flooding of an old drainage way. A similar outbreak occurred at Aurora, Ohio, as a result of damming a small creek for beautification purposes in a new residential subdivision. Paw Paw, Mich., had a small epidemic after increasing the size of its water reservoir. Malaria has occurred as far north as Minnesota in association with impoundages on the upper Mississippi River. The principal sources of carriers for these outbreaks were probably the endemic foci of the South. It should be noted particularly that the outbreaks occurred in association with impounded water.

A study of the distribution of malaria in the United States during different periods since 1882 (fig. 4) indicates the trend of malaria recession to the Southeastern States. Shown also is the possibility of reinvasion of places from which malaria has retreated. Malaria is never a static entity, least of all in the North Temperate Zone, either in its local manifestation or in its geographic distribution. The establishment and maintenance of the disease are dependent upon the continued presence of the malaria vector, infected persons, and susceptible, nonimmune persons, both of whom must be accessible to the biting of the vector.

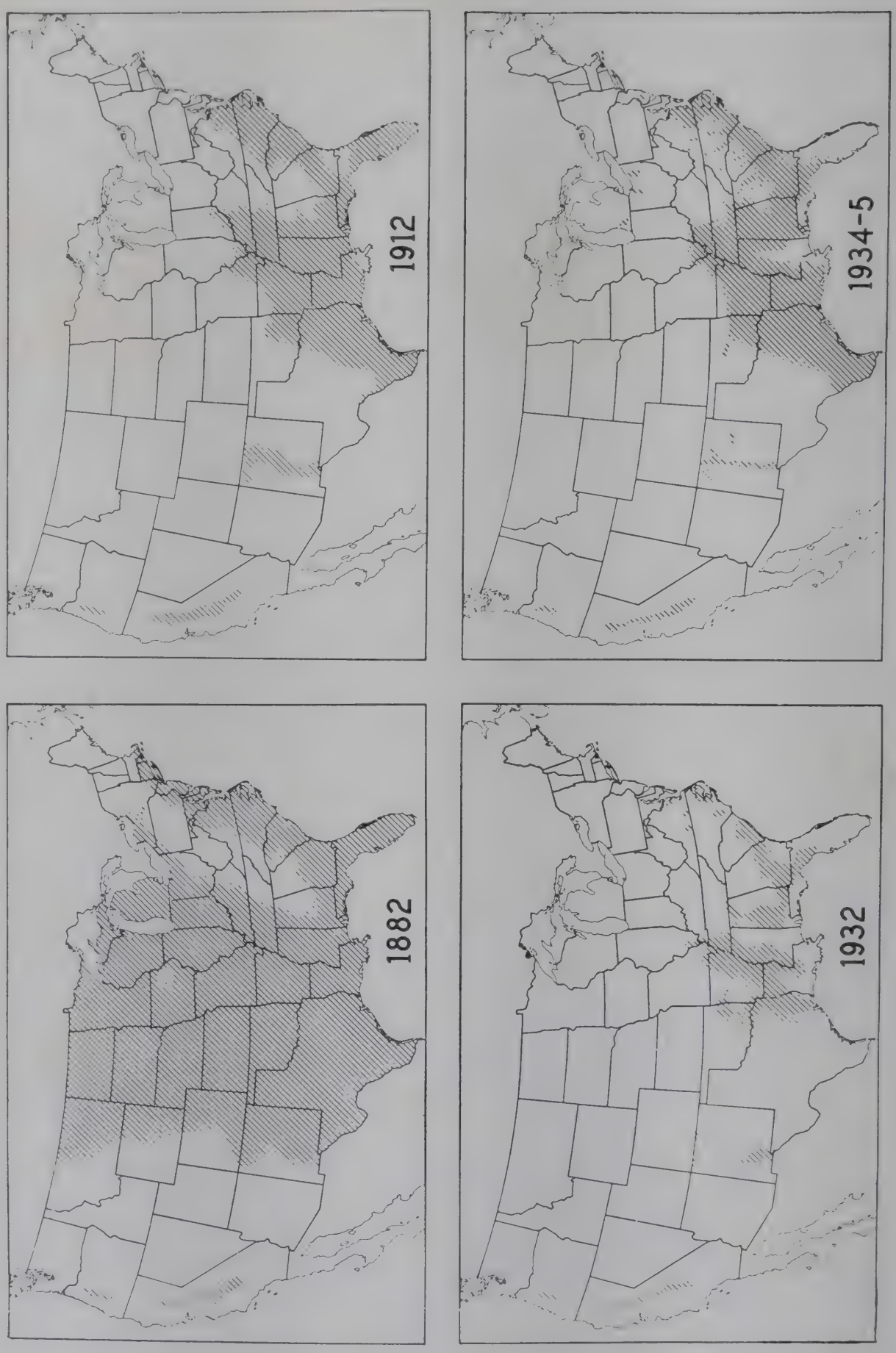

FIGURE 4.—Endemic areas of malaria in the United States (1882, 1912, 1932, and 1935).

At the present time (1946) malaria rates are at the lowest point yet experienced in this country. However, in view of the foregoing, malaria may well recur where high anophelism is allowed to prevail.

EFFECT OF MALARIA ON REGIONAL AND COMMUNITY DEVELOPMENT

Because malaria control is expensive, both initially and from the standpoint of maintenance, some justification must be given for the expenditure of funds for this purpose. The logical justification should, therefore, be in terms of what malaria costs the community in which it occurs.

Dr. Henry Rose Carter, the dean of North American malariologists, once stated, " * * * the loss of efficiency caused by malaria, in malarious sections of the South, is beyond comparison greater than that caused by any other disease, or even by any two or three diseases combined." There is no question but that in regions of relatively high malaria prevalence this disease holds back the general development of the section affected and interferes with the normal growth of local industries. The death rate of malaria in temperate climates, probably less than 0.5 percent of the cases, may not seem alarming, yet in the amount of sickness and suffering, the loss of time, efficiency, and expense, the lowered vitality of those afflicted, and in the reduction of property values, malaria is without a rival among the diseases affecting man.

The cost of malaria is almost impossible to estimate, for the reason that intangible costs are involved which do not lend themselves to objective translation in terms of dollars and cents. For instance, it is difficult to appraise fiscally losses due to physical impairment and loss of efficiency, and the associated expression in reduced income because of inferior crops, inability to attend schools, and similar losses. If it be assumed that each clinical attack of malaria costs $2.50 for medical care plus $7.50 in intangible losses, and that each malaria infection produces a minimum of four clinical attacks, then the average cost of every malaria infection would be $40. When this estimate was applied to the number of malaria cases which occurred in the population living near the Tennessee River in north Alabama, as determined by malaria surveys, it was calculated that malaria produced a loss of some 4 million dollars in the 5-year period 1934-38. Even if this figure is an overestimation by 50 percent of the actual cost of malaria to the north Alabama communities during this period, expenditures of funds up to 2 million dollars would have been justified to control malaria in this area.

As previously mentioned, malaria is never a static entity. With rapid transportation no part of the country where potent anophel-

ism occurs today is safe from the hazard of malaria so long as endemic malaria is occurring elsewhere in the country, and so long as there is importation of malaria carriers from abroad. The probability is that this hazard may even be intensified by increasing international travel.

MALARIA AND IMPOUNDED WATER

History

Perhaps the earliest documentation of the occurrence of malaria in association with impounded water was made by Dr. Charles V. Chapin of Rhode Island in 1882. In discussing the epidemics of malaria which occurred in the Eastern States in the 1870's, he mentioned specifically the outbreaks which occurred near water impounded by construction of railroad embankments. It is probable that some of these small epidemics were precipitated by the return of Union troops who had been infected with malaria in the South during the Civil War.

Long before the discovery of the transmission of malaria by mosquitoes, there are records of dams being blasted by irate citizenry who attributed the local occurrence of malaria to the presence of impounded water. However, it was not until the development of hydroelectric projects south of the Ohio River began in the second decade of this century that the renewed importance of impounded water malaria became apparent. One of the earliest of these impoundages was that of the Tennessee River in 1912 created by Hales Bar Dam. This reservoir was not prepared for the prevention of mosquito propagation, and as a result an epidemic of malaria occurred in the population living contiguous to the shore line. The endemic foci established at that time are still in existence. In 1914 Lay Lake on the Coosa River was impounded with only partial clearing prior to filling. During the first year following impoundage there was a severe outbreak of malaria in the population living along the shores of the reservoir. As a result of this outbreak it was necessary to draw down the reservoir and do additional clearing. There are numerous other examples of malaria epidemics following the impoundment of water, such as the Gantt Reservoir (1923) on the Conecuh River in Alabama which was initially impounded without any clearing, and more recently the Santee-Cooper project (1943) in South Carolina which was impounded after incomplete reservoir preparation.

Litigation resulted from the epidemics of malaria associated with the Hales Bar, Lay Lake, and Gantt projects. The residents of the Hales Bar area sued the Tennessee Electric Power Co., and received a judgment in the lower courts which subsequently was

reversed by the Supreme Court of Tennessee due to the lack of definite scientific information at that time concerning the relation between impounded water and malaria. A similar outcome resulted from other litigation; but owners of impounded water projects began to realize the necessity for malaria control and to undertake it for self-protection.

Investigation of malaria and its control

Because of the evident importance of malaria associated with impounded water, the United States Public Health Service initiated about 1912, and pursued intensively for the next decade, a series of investigations which established clearly the fundamental relationships between impounded water and malaria and the steps necessary for its control.

These basic studies defined the major physical and biological changes which attend the conversion of a flowing stream into a reservoir; they extended knowledge on the bionomics of *A. quadrimaculatus;* and they outlined the fundamentals of the control of *A. quadrimaculatus* propagation on impounded waters. These findings, with supplementary information collected during the past 20 years by other agencies, may be summarized as follows:

The sudden conversion of a flowing stream into a reservoir inevitably results in major physical and biological changes which begin as soon as the pool level rises above the original channel of the impounded stream and continue for a period of several years. The primary physical change consists of permanently or periodically flooding the land lying below the elevation of the spillways of the impoundage structure. Small tributaries become large expanses of quiet water; and the impounded stream, now extending far beyond its flood plains, becomes a broad lake. The shore line of the new lake is straight or tortuous, precipitous or flat, depending upon the topography of the region. Inundated terrestrial vegetation is killed, but its vestiges appear for a long time in the form of floating debris, and, with other types of flotage, produce food and protection for mosquito larvae. In the course of time terrestrial marginal growth becomes replaced by aquatic or semiaquatic vegetation. The extent to which herbaceous marginal plants become established on the shore line depends to a considerable degree on the water level management and the extent of the draw-down during the growing season.

The impounding of a lake in a region of flat topography produces a wide variety of breeding places of *A. quadrimaculatus.* The lower part of such a reservoir usually has a precipitous shore line; the middle portion is characterized by broad expanses of shallow water

(see fig. 9) ; and the upper portion is within the old channel of the river. *Anopheles* propagation is so consistently associated with vegetation alone or with flotage that in the final analysis control of this propagation becomes the control of the conditions that make it possible.

It was found that the adults of *A. quadrimaculatus* mosquitoes emerge after an aquatic life of about 2 weeks during the main part of the summer breeding season. Their dispersion is determined by a number of factors, the principal ones of which are the density of mosquitoes at the place of emergence and the availability of suitable blood supplies near the impounded water breeding places. In general, this dispersion does not extend much beyond a mile. Anophelism (and malaria transmission) is most intense within one-half mile of impounded water. However, with a population scattered throughout the mile zone about a lake and with the occurrence of prolific propagation of mosquitoes, dispersion and some transmission of malaria may extend for more than a mile from a breeding place. The season of active propagation in the southeastern United States is about 20 weeks in duration and is determined by the occurrence of water surface temperatures in excess of 70° F. In general, in the Tennessee Valley the malaria control season is considered to begin about May 15 and to extend to about September 15.

These observations make fairly evident the basic control measures which have to be established to control mosquito propagation on impounded waters. They are, in brief, the proper clearance of reservoirs prior to impoundage; the impoundage of reservoirs as early as possible after the cessation of the mosquito-breeding season (never during the summer) in order to allow floating debris to become waterlogged and sink, or to be stranded by wave action; management of water levels in such a way as to minimize mosquito breeding and retard the invasion of marginal plants; and finally, the annual removal of such marginal growths as may be conducive to the propagation of mosquitoes during the summer months.

These are basic naturalistic control measures which, when properly carried out, are generally quite effective for controlling mosquito production in the average reservoir. However, in reservoirs with extensive mosquito-breeding areas or where naturalistic measures cannot be fully applied, supplementary measures may be required. As no control measure, naturalistic or otherwise, is 100 percent effective and as mosquito propagation follows a geometric curve of increase, it is necessary that man exercise constant surveillance of the situation if he is to prevent excessive production of mosquitoes.

Adoption of State regulations

The studies and recommendations of Carter and his associates of the United States Public Health Service resulted in the adoption of State regulations to govern the conditions under which water might be impounded in order to minimize the danger to public health. One of the earliest regulations enacted was that of Alabama, and this has served more or less as a model for similar regulations by other States. In general, these regulations provide for reservoir clearance, drainage of marginal depressions, and removal of marginal vegetation and debris after impoundage. Some of the State regulations provide for such supplementary measures as water level fluctuation and house mosquito-proofing. Abstracts of all existing State regulations pertaining to malaria control on impounded water are given in appendix A.

Malaria control problems associated with impounded waters

As the foregoing discussion indicates, the impounding of water reverses the normal procedure of drainage for securing control of *A. quadrimaculatus* propagation. Even so, it nearly always happens that impounding a large stream tends to eradicate some preexisting malaria control problems. Since the lower third of the reservoir is nearly always inundated to a considerable depth, those breeding places of *A. quadrimaculatus* which formerly existed in flood-plain collections of water are eliminated. The Wheeler Reservoir in the Tennessee Valley is a case in point. Lawrence County, Alabama, which borders the lower third of Wheeler Reservoir, was formerly one of the most malarious counties in the State, but the malaria was largely confined to population groups living on a plain about 15 miles broad lying between the Tennessee River and a range of low hills to the south. In 1934, a malaria survey conducted within 1 mile of the high water contour of the lake and between this contour and the banks of the river revealed that more than 60 percent of the blood films collected contained malaria parasites. The perpetuation of malaria in this population group was due to mosquito propagation in lime-sink ponds and in flood plain collections of water. The latter were completely inundated in 1937 when the lake was impounded, and the larger ponds were connected with the lake by a series of canals which permitted fluctuation of their water levels with the lake pool level. The result has been a gradual disappearance of malaria in this section to a level below 1 percent.

Thus, impoundage of water in situations where malaria existed prior to the impounding may actually result in an alleviation of the problem. On the other hand, the preexisting situation may be made measurably worse by increasing the possibilities for mosquito

propagation. It is held by many malariologists that the anopheline biting rate is the most important variable in the epidemiology of malaria. Therefore, in situations where the biting rate is increased, malaria of low endemicity may be converted into malaria of epidemic proportions, followed by a higher level of endemicity than existed before the creation of the lake. The cited examples of outbreaks of malaria associated with impounded water projects are cases in point.

The impoundment of water in places where malaria has not occurred in the memory of man will be followed almost invariably by the propagation of *A. quadrimaculatus* even though no evidence of the presence of this mosquito can be found prior to creation of the lake. An example is the large storage reservoir created by Norris Dam in upper east Tennessee. Prior to 1935 careful search failed to reveal propagation of *A. quadrimaculatus* in the vicinity of this reservoir area. In the summer of 1935 a small tributary of the Clinch River was impounded for recreational purposes. This was followed by an explosive appearance of *A. quadrimaculatus*. Subsequent to impounding the lake itself in 1937, *A. quadrimaculatus* propagation sufficient to create a malaria hazard occurred in certain portions of the lake.

Aside from the certainty that *A. quadrimaculatus* propagation will occur on impounded water unless preventive measures are taken, there are two important factors which contribute to the malaria producing potentialities of such reservoirs. One is the fact that with modern transportation a person may be inoculated with malaria in Florida and have his primary attack in Oregon; the other that large bodies of water offer recreational facilities which are chiefly utilized during the mosquito-breeding season. Almost inevitably, sooner or later, gametocyte carriers will complete the epidemiological equation necessary for malaria transmission.

RESPONSIBILITY FOR MALARIA CONTROL ON IMPOUNDED WATER

The impoundage of water in portions of the United States where malaria is endemic has so frequently led to local enhancements or extensions of malaria prevalence that malaria prevention is now regarded as a definite responsibility of the water impounder. This responsibility has as its legal basis the owner's obligation to the people affected by an impoundage not to create a condition which may cause them to have malaria. The basic concept involved is that through changed land use, a hazard to the public health is introduced.

Artificially impounded water represents a change in the use of

land brought about by the impoundage. The zone of influence of a reservoir often embraces land other than that of the individual, organization, or agency impounding the water, and affects the people occupying or visiting such land. The resultant conditions are, therefore, of public concern. Thus, if an environment favorable to the propagation of anopheline mosquitoes has been or will be created by the impoundage of water, it is the direct responsibility of the owner to carry out whatever measures are necessary to prevent the transmission of malaria. Applicable laws and malaria control regulations, which have been established for the protection of the public health, define this responsibility, and provide guidance for owners who create and maintain artificial impoundages.

As with a majority of laws designed to protect public health, the principal regulatory powers concerning malaria prevention reside with State or local governments. Customarily most of the regulatory authority is exercised by the States. In order to accomplish the desired goal, State departments of health in the malarious region have provided epidemiological, laboratory, and engineering services to assist with the planning and direction of measures necessary for the control of malaria. The United States Public Health Service engages in control activities through and with State health agencies. In some instances, technical and consultant services are furnished direct to other Federal agencies. The interstate coordination of activities and dissemination of knowledge are also important functions of the Public Health Service with respect to malaria control on impounded water.

Responsibility for malaria prevention in connection with water impoundments has been generally accepted by government agencies such as the Tennessee Valley Authority, United States Corps of Engineers, Department of Agriculture, and the Department of the Interior; by private corporations, such as power, mining, and other industrial organizations; and, to a lesser degree, by private small impoundment owners.

In meeting owner responsibilities, the most effective approach to malaria control on water impoundments is suppression of the mosquito vector through prevention of its production. Moreover, this method is most suitable for use by the owner of the impoundment, in that control measures are confined to the reservoir property where adjustments can best be made to meet the hazard created. Other antimalaria measures, such as mosquito-proofing and house-spraying, should be considered as supplementary practices and utilized to support antilarval measures. Such secondary measures are less dependable because they are never fully within control of the

impoundment owner, and they depend to a considerable degree upon the cooperation of the individuals affected. Application of these controls, when circumstances require their use, should not be the responsibility of the people in the malarious environment which has been created.

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II. PLANNING MALARIA CONTROL

BASIC ELEMENTS OF PLANNING

Whenever a stream is impounded for navigation, power, recreation, flood control, or any other purpose in a malarious or potentially malarious region, the resulting lake may create a public health hazard to the people in the vicinity unless appropriate measures for malaria prevention and control are carried out. For this reason, provisions for the control of malaria should be incorporated into the basic design, construction, and operation of any impoundment created in such a region. Adequate planning in the initial stages of the project will also result in increased effectiveness and economy.

The first step in the development of a malaria control program for a given project is to make a careful appraisal of the existing and potential problems relating to malaria transmission. This appraisal will involve studies of the epidemiological, biological, and engineering aspects of malaria prevalence, and of the production and control of the malaria vector. These studies will make it possible to predict approximately the potential effect of the impoundment upon the production of mosquitoes and the transmission of malaria, and will furnish the information necessary for the formulation of an adequate control program.

After the malaria problem has been ascertained, consideration must be given to the selection of control measures which will meet the problem. Methods for the control of malaria may be divided into (1) measures directed at the mosquito vector, (2) measures directed at preventing contact between man and the malaria mosquito, and (3) measures directed at the malaria parasite. These methods of control may also be divided into those which are of permanent value and into those which require repetitive application. A summary outline of measures which may be utilized in the control of malaria on impounded water is given below.

I. Measures directed at the malaria mosquito
   A. Against the larvae (antilarval)
      1. Elimination of breeding habitat
         (a) Filling and deepening (permanent)
         (b) Dewatering (permanent)

2. Alteration of breeding habitat
   (a) Clearing (permanent)
   (b) Water level management (repetitive)
   (c) Marginal drainage (permanent)
   (d) Control of vegetation (repetitive)
3. Chemical control of larvae (repetitive)
   (a) DDT—paris green—oil—pyrethrum, etc.
4. Use of predators

B. Against the adult mosquito
   1. Residual house-spraying (repetitive)
   2. House air-spraying (repetitive)
   3. Area air-spraying—DDT (repetitive)

II. Measures directed at preventing contact between man and the mosquito
   A. Mosquito-proofing (semipermanent)
   B. Depopulation or restriction of land use to daytime occupancy (permanent)

III. Measures directed against the parasite
   A. Treatment of patients and carriers (repetitive)
   B. Chemoprophylaxis (repetitive)

In light of present knowledge, the most desirable approach to the control of malaria is through an attack on the anopheline vector. This usually involves either the prevention of mosquito breeding or the control of the vector in the larval stages. The most reliable method of control is to eliminate permanently mosquito-breeding areas or to render them unsuitable for the production of mosquitoes. It is practically impossible to eliminate adult mosquitoes after they have emerged, difficult to protect man completely against mosquitoes, and almost impossible to control the malaria parasite with methods now available. A more detailed discussion on the selection of control measures is given subsequently in this chapter.

Of primary importance in the planning of any reservoir malaria control program is the location and height of the dam, the water level operating schedule, and the water control facilities. If the dam is located in a mountainous region, where the adjacent population is relatively sparse and the shoreline of the lake is generally steep, the malaria control problem will not be complex. In such locations the usual antilarval measures of clearing, marginal drainage, shore-line maintenance, and the application of larvicides at times of unfavor-

able water levels will usually be adequate. However, the areas around reservoirs in regions of flat topography are usually well developed with a relatively high population density. The flat topography increases the anopheline production potential and limits the effectiveness of water level management. These factors tend to create a very complex malaria control problem, particularly in regions where malaria is endemic.

In considering the design of the dam and the water level control structure, particular attention should be given to selecting the elevations which will minimize the creation of shallow problem areas, particularly near towns or communities. Experience in the past has revealed instances where, by a slight change in operating water levels, flat shallow problem areas near concentrated population centers could have been avoided.

The general water level operating schedule for a reservoir will be determined primarily by the purposes for which the project is constructed and by the stream flow. However, whether the project is constructed for power, navigation, irrigation, flood control, recreation, water supply, wildlife conservation, or any combination of these, it is essential that the needs for malaria control purposes be weighed along with other needs in the planning of the water level operating schedules. Wherever possible, the design of the dam should include means for fluctuation of the pool, seasonal drawdown, and raising the water level above the basic clearing line to strand drift and flotage.

After the establishment of the probable water level schedules, plans should be made for preparation of the reservoir. The development of these plans requires close collaboration between personnel responsible for the professional aspects of malaria control and those responsible for reservoir construction. In addition to the development of specifications for clearing, plans must be formulated for the drainage or connection of the marginal depressions below the spillway or maximum elevation of the pool, so that they will drain or fluctuate with the main body of the lake. Where land-use restriction is utilized as a malaria control measure, clearing and drainage may not be necessary.

As malaria control should be planned on a long-term basis, consideration should be given in the initial planning of reservoir preparation to improvements of the shore line which will permanently eliminate or minimize areas favorable to the production of malaria mosquitoes. (See ch. IV, "Permanent Marginal Measures".) Substantial capital expenditures for such construction to reduce the malaria control problem may frequently prove to be a good invest-

FIGURE 5.—Malaria control operations for Pickwick Reservoir—July 1, 1943 to June 30, 1944.

ment over a period of years as more effective control will be obtained with reduction in annual costs.

Planning malaria control operations requires detailed maps of the reservoir, preferably mosaics and line maps of two scales—one with a scale of about 1 inch equals 500 feet, and another with a scale of about 1 inch equals 2,000 feet. These maps should show roads, streams, property lines, marshes, lakes, ponds, woods, houses, etc., in the reservoir and its environs. They should show especially the contours of the maximum pool, maximum "mosquito-control" elevation, and the minimum "mosquito-control" elevation. In addition, for relatively constant level reservoirs, it would be desirable that the maps show the intermediate contours 1, 2, 3, and 4 feet below the maximum "mosquito-control" elevation. (See "Basic Clearing Line," ch. III, for definitions.)

In the development of a malaria control program, it is most important to anticipate the necessary personnel, facilities, and equipment for preparation of the reservoir; shore line maintenance; supplementary or emergency measures, such as larviciding, mosquito-proofing, and house-spraying; and for appraising control measures. Of course, the facilities and equipment required will be governed by the control measures employed and are discussed briefly in subsequent chapters on the various measures of malaria control.

After the definition and analysis of the malaria control problem, engineering estimates of the work, materials, equipment, and costs should be prepared. Such estimates should include a map of the reservoir showing the location of the proposed work; a tabulation of units of work and quantities of materials; a cost estimate by types of measures in terms of personnel, materials, equipment, and services; per capita cost for malaria protection; and a statement of program justification. An example of an engineering estimate for a routine malaria control program is given in tables 1 and 2 and in figure 5.

In evaluating the malaria problem and in the initial stages of planning it will usually be possible for the organization impounding the reservoir to secure technical assistance from the official health agency having jurisdiction. After the need for malaria control measures has been established, a malaria control service should be organized within the agency responsible for the reservoir to direct and supervise the planning and application of malaria control measures. The size of such an organization will, of course, depend upon the malaria problem and extent of the control measures, but regardless of size, the personnel within it should be experienced in malaria control on impounded water.

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TABLE 1.—*Engineering Estimate of Units of Work and Quantities of Materials Malaria Control Operations, Pickwick Reservoir*

(July 1, 1943–June 30, 1944)

WORK

	Miles of shore line	Acreage	Man-hours	Machine hours
Total miles of shore line	496	—	—	—
Mosquito control zone	—	3,000	—	—
Shore line improvement	118	370 to 1,100	22,600	525
Percent of total	24	12 to 37	—	—
(*a*) Coppice removal	—	—	—	—
(*b*) Annual growth removal	106	735	18,400	525
(*c*) Aquatic growth control	—	2	500	—
(*d*) Drift removal	7	—	880	—
(*e*) Drainage maintenance	—	—	2,000	—
(*f*) New drainage ditches	—	—	820	—
Larvicidal operations[1]	181.5	740	9,600	—
Percent of total	37	25	—	—
(*a*) Airplane dusting	49	700	300	40
(*b*) Boat and hand dusting	2.5	40	300	—
(*c*) Boat and hand oiling	130	—	9,000	—

[1] Larvicidal operations are based on the assumption of 6 applications during the period May 15 to July 15.

LARVICIDAL, HERBICIDAL, AND ARBORICIDAL MATERIALS

	Pounds
(*a*) Larvicidal dust (22 percent paris green mixture)—airplane application	34,000
(*b*) Larvicidal dust (16 percent paris green mixture)—boat and hand application	2,000
	Gallons
(*c*) Larvicidal oil (1 part black oil, 9 parts kerosene)	38,000
(*d*) Herbicidal oil (kerosene)	2,000

INSPECTION

	Man-hours
(*a*) Mosquito larvae inspection	2,500
(*b*) Mosquito adult inspection	925
Total	3,425

TABLE 2.—*Cost Estimate of Labor and Materials Malaria Control Operations, Pickwick Reservoir*

(July 1, 1943–June 30, 1944)

PERSONNEL, SALARIES, AND WAGES

No.	Classification	Rate	Time employed	Total cost	Larviciding		Shore-line maintenance	Equipment maintenance
					Boat	Plane		
1	Principal Engineering aide	$3,163	Full time	$ 3,160	$ 1,385	$195	$1,340	$240
1	Senior Engineering aide (part time)	2,798	¼ time	700	290	45	290	75
4	Foremen	1,620	½ time	4,560	1,715	265	2,010	570
9	Boat operators	0.625	650 hours	3,670	2,200	—	1,470	—
9	Laborers (larvicidal)	.525	955 hours	4,360	4,080	—	—	280
2	Laborers (airplane)	.525	150 hours	160	—	160	—	—
22	Laborers (shore-line)	.525	865 hours	10,000	—	—	10,000	—
	Total salaries and wages	.....	.....	26,610	9,670	665	15,110	1,165

MATERIALS AND SUPPLIES

	Total cost	Larviciding		Shoreline maintenance	Equipment maintenance
		Boat	Plane		
Larvicides:					
Oil, 40,000 gallons @ 10 cents	$4,000	$3,800	—	$200	—
Dust, 18 tons @ $100	1,800	100	$1,700	—	—
Fuel:					
Gasoline, 6,000 gallons @ 12 cents	720	430	—	290	—
Motor oil, 450 gallons @ 20 cents	90	55	—	35	—
Transportation and travel:					
Truck and car, 15,000 miles	750	150	135	150	$315
Per diem	150	75	25	50	—
TVA dusting airplane:					
Standby charge	1,000	—	1,000	—	—
Flying, 40 hours @ $25	1,000	—	1,000	—	—
Supplies, spare parts, miscellaneous	1,500	100	—	150	1,250
Equipment rental	500	—	—	500	—
Depreciation	4,700	3,150	—	1,550	—
Services of other divisions	3,500	500	—	150	2,850
Total materials and supplies	19,710	8,360	3,860	3,075	4,415
Grand Total	46,320	18,030	4,525	18,185	5,580

The basic elements of planning malaria control on impounded water have been discussed in the preceding paragraphs. The following sections are an amplification of those elements dealing with the definition of the malaria control problem, selection of control measures, personnel, and integration of malaria control measures into the planning and construction of a reservoir.

DEFINITION OF THE MALARIA CONTROL PROBLEM

As previously mentioned, the first step in planning a malaria control program is to obtain a clear definition of the problem. Factors which should be considered in such an investigation are prevalence of malaria prior to impoundment, population density and housing conditions within 1 mile of the maximum pool contour, topography and climate, anopheline prevalence prior to impoundment, character and extent of malaria mosquito-breeding areas which will be created by the impoundage, general ecology of the area, particularly the type of soil and vegetation; location of natural mosquito-breeding areas outside the reservoir proper; operation of the reservoir and probable water level schedules; and classification of the shoreline. Data on these various factors are necessary for predicting the potential malaria problem, for planning and estimating the required malaria control measures, and for comparing post-impoundage mosquito and malaria prevalence with the conditions existing prior to impoundage.

Epidemiological surveys

For intelligent planning and operation of a malaria control program, it is essential to know the distribution of the population and

the prevalence of malaria in the areas contiguous to the reservoir. A general knowledge of malaria prevalence may be secured from local physicians' reports of malaria mortality and morbidity; however, such information is usually not complete and should be used only as a guide to locate endemic areas. In general it will be advisable to conduct a detailed malaria survey which may include a census of all families living in the area to be flooded as well as within the 1-mile zone from the contour of the maximum pool of the proposed reservoir. The data collected should include length of residence; ownership; mosquito-proofing of houses; age, sex, and color of occupants; and a blood film and malaria history of each member of the family. As many annual blood film surveys as feasible should be made after approval of the project. The results of the statistical study and the malaria survey should be plotted on suitable maps (fig. 183) to show the location and number of malaria cases. In addition, these maps should indicate mosquito-breeding areas in the reservoir and its environs (2-mile zone), and the results of anopheline mosquito surveys.

In order to keep informed of the effect of impoundage on the transmission of malaria and the effectiveness of control measures, annual malaria surveys should be continued after impoundage. Valuable supplementary information in this connection can also be obtained through follow-up of malaria cases reported by field men and local physicians. As the actual and potential problem varies from section to section of a reservoir, these epidemiological findings will not only provide a measurement of the effectiveness of the work but also furnish a guide as to where special efforts should be directed or supplementary measures applied.

A detailed discussion of malaria survey methods and techniques is given in chapter XII.

Population density and housing conditions

Housing conditions and density of population in relation to potential anopheline breeding areas are of particular importance in the consideration of control measures, both from the type of measures to be applied and their relative cost. For example, rather intensive antilarval measures and permanent shoreline improvement may be required for the protection of nearby cities, towns, rural communities, camps, industries, and recreational centers while, on the other hand, in sparsely populated areas it may be more advisable to restrict land use in the area or apply such secondary control measures as mosquito-proofing and residual house-spraying. There may be some portions of the reservoir more than 1 mile from any human habitation where no malaria control measures are necessary.

The conditions of the houses and the extent to which they are mosquito-proofed are important in evaluating the protection from malaria transmission which existing housing would offer at times of unexpected or uncontrollable mosquito production.

Climate and topography

Climate and topography in the "mosquito-control" fluctuation zone are most important in considering the anopheline production potential of a reservoir and in defining the malaria control problem.

Climatological factors which have a bearing on mosquito propagation, and which should be ascertained, are rainfall, humidity, mean annual and summer air and water temperatures, and average dates of first and last killing frosts. The effect of air and water temperatures on the initiation and amount of mosquito breeding is discussed in chapter XI.

Topographical features which should be determined are principally the extent of shallow areas in the fluctuation zone and the exposure to wind and wave action. These potential shallow areas and marginal pools should be located and plotted on the general reconnaissance survey map. The variable effect of topography on a mosquito control program is well illustrated by the scant mosquito production on storage reservoirs with exposed, steep shore lines, as contrasted with the heavy production experienced on main-river reservoirs with extensive, shallow, wind-protected margins.

Entomological surveys

Before procedures can be formulated for an adequate malaria control program on an impounded water project, the anopheline production potentials of the reservoir must be carefully evaluated. Likewise, following impoundment, the success of mosquito control measures are determined by routine inspections for larvae and adults of the malaria vector or vectors. Constant entomological observations are required in making adequate epidemiological appraisal. Entomological studies are also an essential requirement for improving the effectiveness and economy of a control program.

Before a reservoir is impounded, mosquito surveys should be made in its vicinity to determine: (1) the species of mosquitoes present and their relative abundance, particularly the anophelines; (2) the species which are vectors of malaria; (3) the present and potential breeding areas of the malaria vectors; and (4) the ecology of the malaria vectors, particularly the type of environment in which they breed, and the blood-feeding habits and flight range of the adult mosquitoes. The preimpoundage mosquito survey should include,

if possible, periodic observations as to anopheline densities in the area over a period of one or more seasons. Such periodic observations will provide information on the seasonal beginning and ending of anopheline production and a basis for comparing mosquito production prior to impoundage with that after impoundage.

In making the survey, particular attention should be given to the location of breeding areas of the species of mosquitoes which are vectors of malaria. In the United States, these species will be found where there is shallow, warm water, with an abundance of vegetation and flotage. The survey should include both dipping for larvae and searching natural resting places for adult mosquitoes. It is important to give attention to the location of potential as well as actual breeding areas.

The selection of mosquito-catching stations, mapping, and the techniques for making pre- and post-impoundage mosquito observations are discussed more fully in chapter XI.

Soil and vegetation

The character of the soil and flora in the "mosquito-control" fluctuation zone has a significant bearing on mosquito breeding conditions and, in turn, on the program and its cost of application. For this reason, the reconnaissance survey should include a study of the timber in the basin (acreage to be cleared, density, predominating species, and tolerance to flooding); soil conditions (type of soil—whether fertile or poor, or clay, sandy, gravelly, or rocky); and the existence, location, and extent of marginal and aquatic plants which are known to create anopheline mosquito control problems when such plants become established in the reservoir.

The fertility of the soil has a significant bearing on the type of vegetation and its rate of development, and in turn the character of the vegetation determines to a considerable extent the natural protection afforded the larvae and the abundance of their food supply (ch. XI and ch. XIII). The type of vegetation will also affect shore line maintenance operations (ch. VI) and the application of larvicides (ch. VII).

Water level schedules

The proposed water level schedule is of primary importance in appraising the potential mosquito production and formulating a malaria control program for a reservoir. Water level schedules not only affect current mosquito production but also influence the growth of marginal vegetation and, consequently, the selection of control measures and the ultimate cost of the malaria control program. The principles of water level management and its relation to mosquito production, shore line maintenance, the application of

larvicides, and plant control are discussed in chapters V, VI, VII, XI, and XIII.

In planning a water level schedule for a reservoir it is necessary to consider:

(a) Primary purpose or purposes of the project—whether for flood control, power, navigation, water supply, irrigation, recreation, wildlife, or a combination of these.

(b) Stream flow and volume of storage in the fluctuation zone—the probability of filling each year, amount of fluctuation possible, and the seasonal recession are all functions of these two items.

(c) Design of the dam and the water level control facilities—the maximum pool level, flood surcharge, and rate and extent of recession, all depend upon the type of design, elevation, and capacity of the control facilities.

(d) Topography and vegetation in the fluctuation zone—a steep, rugged shore line exposed to wave action will require much less precise water level management than a shore line of extensive, flat, shallow areas; and water level fluctuation is sometimes ineffective for mosquito control where the shore line or margin is colonized with certain types of marginal or aquatic vegetation.

Classification of the shore line

In analyzing the malaria control problem it may be desirable to divide the reservoir into areas or zones classified according to their potentialities for the production of malaria mosquitoes. This may be especially indicated on large run-of-river projects where there is frequently a wide variation in conditions relating to mosquito production in various parts of the reservoir. Such zonation is particularly useful in the selection of control measures and for recording the progress, cost, and effectiveness of postimpoundage maintenance operations.

By proper consideration of the topography, soil characteristics, and water level operation schedules, it is usually possible to estimate with a considerable degree of accuracy the sections of the margins which will develop the most favorable breeding conditions for mosquitoes.

Criteria which have been used for classifying the margins of reservoirs on the Tennessee River are given below:

Type I.—Situations characterized by prolific and extensive production of mosquitoes under conditions very difficult or even impossible to control.

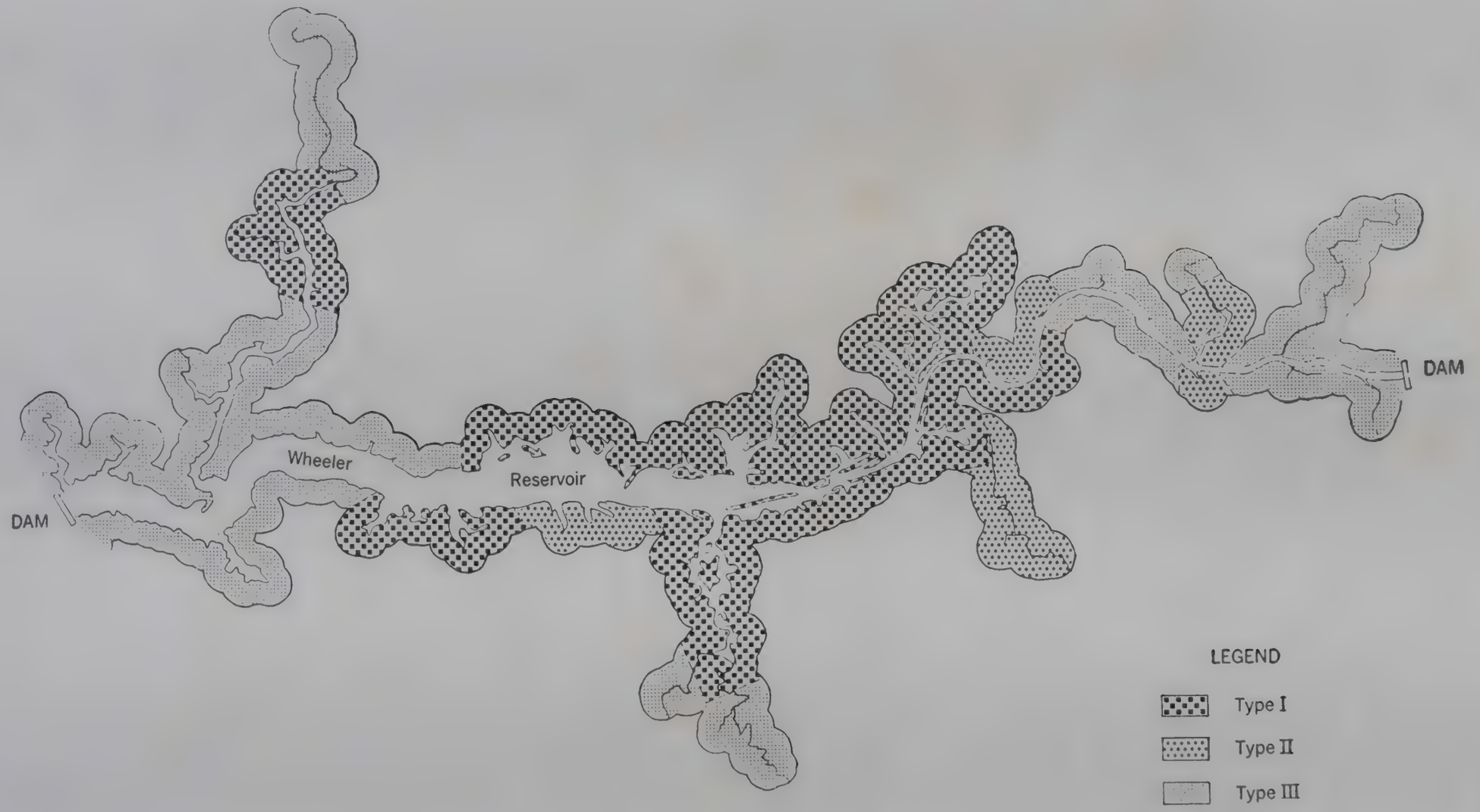

FIGURE 6.—Typical classification of shore line of a main-river reservoir. Wheeler Reservoir, Tennessee River.

Type II.—Situations characterized by moderate to prolific breeding of mosquitoes always possible of control, although such control may be either difficult or easy to accomplish.

Type III.—Situations characterized by intermittent, light, or no production of mosquitoes and where control can always be accomplished with ease.

Figure 6 shows a zoning and classification of various parts of the Wheeler Reservoir on the Tennessee River and illustrates the difficult problem normally encountered in the central part of run-of-river reservoirs where water is impounded to a shallow depth over extensive areas of a flat flood plain. (See fig. 9.)

SELECTION OF CONTROL MEASURES

Primary considerations

At the beginning of this chapter it was stated that malaria control measures may be divided into (1) control of the mosquito vector, (2) prevention of contact between man and the vector, and (3) measures directed at the malaria parasite, and that of these methods the control of the mosquito vector is usually the most effective and desirable; also that this objective should be sought through use of the more permanent measures in contrast to those having temporary value or requiring repetitive application.

The actual choice of control measures requires a careful evaluation of the malaria endemicity in the area, the population density, anopheline potentials, water level schedules, and the relative effectiveness, permanency, and cost of the various methods of control which are available. The initial planning and selection of malaria control measures must be closely integrated with the primary functions of the reservoir, the design of the dam, preparation of the reservoir, and other interests such as wildlife and recreational developments. As no two reservoirs are alike, and as individual portions of a given reservoir vary widely in the types of problems which they create, the methods of control must be fitted to the individual reservoir or sections of it. A combination of measures will usually be necessary.

In general, as has been indicated, the most effective and desirable approach to the control of malaria on impounded water is through an attack on the malaria vector, either through the prevention of mosquito breeding by an alteration of its habitat or by an attack on the mosquito in the larval stage. For this reason State health department regulations governing impounded water are intended, in the main, to provide malaria control through the control of the malaria

mosquito. Such control is usually sought by proper preparation of the reservoir, including clearing and marginal drainage, maintenance of a clean shore line, water level management, and the application of larvicides as may be required after impoundage. Such antilarval measures have been demonstrated to be very effective in the prevention of malaria about reservoirs having reasonably steep shorelines and a water level schedule favorable for mosquito control. However, some reservoirs have been impounded in recent years in flat topography where the conventional antilarval approach has been neither effective nor economical. Through preimpoundage investigation, the probability of such a situation developing can be predicted, so that the need for permanent shoreline improvement, land-use restriction, or supplementary measures can be anticipated and planned in advance. Wherever economically justifiable, the control measures selected should be those which offer the most positive control and permanency rather than those requiring repetitive application.

Antilarval measures

The production of malaria mosquitoes on those reservoirs which, in a large part, may be classified as type II or III (see "Zoning") can usually be controlled through an antilarval program consisting of reservoir preparation, water level management, shore line maintenance, and perhaps intermittent use of larvicides. Furthermore, a substantial portion of the shore line of many other reservoirs having limited type I areas can be handled in like manner. Typical type II and III reservoirs are storage projects in relatively steep topography which are filled during the winter and spring with gradual release of water and consequent draw-down of the lake during the mosquito season, and run-of-river reservoirs with relatively steep shore lines where a favorable water level can be provided. Effective mosquito control may be achieved on some of these reservoirs with little or no shore line maintenance or larviciding where the reservoirs are properly prepared and have favorable water level management. In contrast with these reservoirs are others which may require substantial sums in the form of both capital and maintenance costs in order to provide adequate mosquito control.

Antilarval measures are discussed in detail in the chapters on reservoir preparation (III), water level management (V), shore line maintenance (VI), and larviciding (VII).

On some projects antilarval methods as presently developed cannot be relied upon to give adequate mosquito control without excessively high annual expenditures. Typical of these are projects located

in relatively flat topography of river flood plains with water level schedules unfavorable for mosquito control. If there is a substantial amount of type I areas, and more favorable water level schedules cannot be provided, permanent shore line improvement, as discussed in chapter IV, should be considered for the reservoir. It is obviously of the greatest importance that the need and economy of using permanent improvement work be foreseen and planned along with the development of plans for the whole project. Integration of the construction of permanent works for malaria control into the over-all reservoir construction program for the Kentucky Reservoir on the Tennessee River resulted in considerable savings in clearing, drainage, and highway and railroad embankment protection.

Supplementary or emergency measures

In no other antimalaria work do changes and emergencies develop so rapidly and with such unpredictability as on impounded water. Provision should be made, therefore, for adjusting the malaria control program to the demands of unforeseen occurrences, trends, or exigencies. This is an important point to be recognized by management and officials responsible for program approvals and allotments. Frequently, indicated program changes may necessitate increased expenditures for certain items, but there may be savings in other items at a later date. For example, a flood control operation might require unusually high water elevations and abnormal use of larvicides for a period of time, but the extra cost might be compensated by a decrease in the annual growth-removal operation as a result of the flooding minimizing the invasion of marginal growth. In another instance a period of little rainfall and low stream flow might necessitate an abnormally early seasonal draw-down of the water level. This would tend to increase marginal growth invasion and subsequent annual shore line conditioning, but there should be a saving in decreased use of larvicides as a result of the water level recession exceeding the rate of growth invasion.

In planning a malaria control program it is important to make a distinction between the demands of temporary situations as contrasted to those which may be expected to prevail for the predictable future. For instance, a temporary situation might warrant the full-scale use of larvicides, mosquito-proofing (ch. VIII), or house-spraying (ch. IX), with a view of discontinuing such measures when the emergency has passed.

The malaria control program should also be sufficiently flexible to permit adjustments to upward or downward trends in malaria prevalence as determined by epidemiological studies. During

periods of low endemicity it would appear permissible to place less emphasis on the repetitive measures, such as the use of larvicides, even with the result of some increase in anophelism; whereas, under conditions of potentially significant malaria transmission, no such chance could be taken and full protection would be sought through application of adequate malaria control measures regardless of their repetitive nature.

Conventional practices should not of necessity dictate the malaria control approach to be employed in all situations, particularly if a more promising or economical approach is available. This would apply especially in an emergency occasioned by transitory situations. For example, the houses in selected areas bordering the central portion of Wheeler Reservoir were mosquito-proofed in lieu of the application of larvicides on the lake. Larviciding, under the conditions, was resulting in only a small degree of mosquito control, and the anophelism from the reservoir was being augmented by production from bordering natural breeding areas. Mosquito-proofing of houses in the 1-mile zone was applied and maintained for considerably less money than would have been required for the continued repetitive use of larvicides and offered better protection under the existing conditions.

At the beginning of the chapter it was stated that each reservoir should be considered an individual problem in planning the malaria control program in advance of construction and impoundage. Similarly, maintenance after impoundage will require adjustment of the program to changing conditions in the reservoir and to the development of new methods, techniques, and information. During the 30 years since malaria control practices were first applied on impounded water projects there has been a continuous succession of developments resulting in improved methods of control.

There are now available to the malariologist many malaria control measures which have been demonstrated and tested. The outlook is that additions to the list will be made presently in the form of improved larvicides, adulticides, herbicides, methods and equipment for applying the control measures, and in the chemotherapy of malaria. The planning of a malaria control program on an impoundage, therefore, should be based on the latest information with a view of including new approaches as their effectiveness can be demonstrated. Persons in charge of the malaria control program should assume responsibility to provide an adequate malaria control protection, but at reasonable cost and offering the least interference with the primary objectives of the project.

MALARIA CONTROL PERSONNEL

The proper planning and application of malaria control measures on impounded water require personnel specially trained in the fields of malariology, biology, and engineering. For relatively small projects most State health departments can provide or arrange for special services needed in these fields for developing an effective malaria control program. However, the owners of the project would be expected to employ the personnel required for routine collection of data and the application of control measures. In the case of major impoundages, such as the Tennessee River development, the flood control projects of the United States Corps of Engineers, and large hydroelectric projects, the technical services which are provided by the State health departments should be augmented by specially trained personnel employed by the operating organization. This would not be a duplication of an existing service since the volume and character of the work necessitate that personnel for planning, executing, and appraising malaria control be within the owner's administrative organization. Furthermore, the personnel employed by the owner will be performing services required in meeting his individual responsibility as distinguished from those services provided by governmental agencies in meeting a common or public responsibility.

The advisability of the owner's providing the technical personnel required to plan, direct, and appraise the malaria control program on multipurpose projects is obvious. The malaria control program on such projects must be integrated with flood control, navigation, power development, irrigation, wildlife conservation, etc., and the management of any marginal lands which may be acquired as a consequence of the impoundage. Furthermore, "on the spot" technical services are needed for the "day-to-day" planning and field direction necessary for efficient application of malaria control measures and for integrating them with primary functions of the project. As reservoirs usually undergo a progressive change in conditions relating to mosquito production and malaria control, competent technical services, supplemented by continuing research and experimentation at the "grass roots" of the problem are necessary to keep the malaria program attuned to new developments and changing conditions in the reservoirs. The personnel employed by the owner of the impounded water projects should cooperate fully with Federal, State, and county health organizations, for these organizations have an interest and concern in the application of malaria control measures on impounded waters.

To obtain basic information relative to the prevalence of malaria, and to malaria mosquitoes and their breeding habitats, the services of personnel with adequate training in the fields of malariology and biology are required. The utilization of this information in the development and application of control measures requires competent engineering personnel. The size of the reservoir will determine the personnel required; however, a desirable organization is one in which the development, planning, and appraisal of the malaria control program are the joint responsibility of a malariologist, a biologist, and an engineer, with the actual application of control measures being under the direction of a well-trained engineer experienced in malaria control on impounded water.

INTEGRATION OF MALARIA CONTROL INTO THE GENERAL PLANNING, CONSTRUCTION, AND OPERATION OF A RESERVOIR

As pointed out in this and other chapters, the malaria control program should be planned and applied so as to offer the least conflict with the normal purposes of the reservoir and the incidental beneficial uses of the water. It should be recognized, however, that occasional adjustments in the normal uses, particularly water level management practices, may be necessary in avoiding prolific production of the malaria mosquitoes and possible malaria transmission.

The preparation of a reservoir involves many program activities, varying in scope and magnitude, depending upon the location of the project and purpose for which it is being constructed. The land to be flooded must be purchased or easements acquired; families living on such land moved out and relocated; existing highways and railroads raised and protected, or relocated; navigation hazards removed and channels and harbors marked and prepared; the reservoir itself cleared of standing timber, buildings, fences and other undesirable objects; and marginal drainage ditches constructed.

Since malaria control is related to both the normal and incidental uses of the project, it is necessary in the interest of efficiency and economy that the measures be integrated into the general planning, construction, and operation of the reservoir. It is the purpose of this section to discuss briefly some of the more important items requiring such integration.

Land for reservoir purposes may be obtained through purchase in fee simple or through acquirement of flowage rights. From a malaria control standpoint, fee simple purchase of land is more desirable than purchase of flowage easements because (1) a marginal

strip of land around the lake is usually included which will facilitate larvicidal and shore line maintenance operations; (2) frequently, for a relatively small additional cost, particularly where payment of severance damage is required, additional tracts of marginal land may be purchased and residents moved who would otherwise require protection from malaria; (3) control of marginal lands permits the better development of a program of grazing along the shore to reduce annual shore line maintenance costs; and (4) control of marginal lands can be used to prevent development of overnight recreational facilities in potentially hazardous malarial areas of the reservoir. The purchase of such excess land need not interfere with its productive use for agriculture, cattle grazing, or growing timber. The cost of managing or renting the land for this purpose, however, is an item of maintenance which should be considered.

Where the purchase of flowage easements is used to obtain the right to flood the land, it is also advisable to provide for the right to do drainage, clearing, and larviciding, as required along the margins of the reservoir, even though it may increase the initial cost to some extent.

It is important to anticipate special needs for land in the malaria control program during the early stages of planning in order to permit an orderly land acquisition program. Lands for malaria control are needed in such situations as (1) sites required for operation facilities including boat bases, airplane landing fields, and storage; and (2) areas to be restricted to daytime use by acquisition in fee simple or purchase of easements. Purchase of land in malaria control dewatering projects might be avoided if sufficient protection from flooding can be assured, otherwise purchase would be required.

Existing highways and railroads to be affected by an impoundage may be relocated, abandoned, or raised in place. Situations may be encountered where it would be possible to utilize such fills and associated borrow pits as part of the diking and drainage system.

In other parts of a reservoir, borrowing operations for highway and railroad construction might be planned so as to provide boat channels and harbors for malaria control operations. Generally, bridges and culverts should be designed to provide adequate clearance for malaria control boat operations after impoundage. Where highways and railroads cross flat, shallow areas, an opportunity may be presented for excavating the necessary borrow for the fills in such a way as to deepen bordering shallow areas and thus eliminate them as potential mosquito-breeding areas at very little increased cost. Borrow pits located above the maximum "mosquito-control" elevation should be constructed to drain when the lake is at a lower pool

level. Mosquito control drainage plans in the vicinity of highway and railroad projects should also be correlated with the plans for drainage structures on such projects.

The possible development of recreational facilities and wildlife refuges should be coordinated with the planning for malaria control. For example, early definition of the potential malaria hazard in various parts of the reservoir will permit selection of areas for recreational development where such hazards will be at a minimum.

Where the wildlife potentialities of a reservoir are to be developed, it is important that plans be prepared and coordinated with plans for malaria control prior to impoundage. For instance, dewatering projects constructed primarily for malaria control might be managed also in the interest of waterfowl. Land-use restriction for malaria control might permit use of the adjacent portion of the reservoir for maximum development of wildlife potentialities. Conversely, the establishment of forest preserves and wildlife refuges, in which no dwellings are permitted within mosquito flight range of the lake, will result in considerable saving on malaria control maintenance operations. A detailed discussion of the interrelationship of malaria control and wildlife conservation may be found in chapter XIV.

The integration of permanent shore line improvement and water level management with plans and operation of an impounded water project is discussed in chapters IV and V.

III. RESERVOIR PREPARATION

GENERAL

Adequate preparation of the reservoir basin is fundamental to the achievement of satisfactory mosquito control after impoundage. In fact it is practically impossible to control the production of mosquitoes on a reservoir which has not been properly prepared. For this reason, State health department regulations place particular emphasis on provisions for clearing, inasmuch as mosquito control by basic antilarval measures is the most effective approach to malaria control which has yet been developed. Usually, clearing renders most of the water surface of a reservoir unsuitable for mosquito production. Figure 7 illustrates conditions created where a reservoir was not cleared prior to impoundage. The objective of reservoir

FIGURE 7.—Typical anopheline breeding conditions resulting from impoundment of an uncleared reservoir.

preparation measures is to clear, drain, and otherwise prepare the basin so that a clean water surface and a clean shore line will exist throughout the reservoir, and so that all marginal ponds, sloughs,

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and depressions will fluctuate freely with the main lake. Anopheline mosquito production should be negligible on a reservoir so prepared and maintained, and having adequate water level management. There are, however, practical limitations to the degree to which these conditions can be achieved and maintained, but in general, these requirements for mosquito control can be accomplished at a reasonable cost. The preparation of each reservoir is an individual problem and must be approached on the basis of existing conditions and those expected to prevail and develop after impounding.

The principal reservoir preparation measures are clearing, marginal drainage, and final conditioning of the fluctuation zone. The term "clearing" includes removal of underbrush, trees, vines, fences, bridges, houses, barns, and sheds. For mosquito control purposes, it is not necessary to clear the deeper portions of a reservoir where all timber would be permanently and completely submerged, but other program interests, principally navigation and protection from floating debris, of various outlet structures at the dam, are often of sufficient importance to make complete clearing of the basin essential. Marginal drainage ditches are required for a twofold purpose; namely, to provide fluctuation of marginal ponds, sloughs, and depressions with the main lake, and to provide boat access for inspection and application of larvicides. They also serve a useful purpose in guarding against the stranding of fish. In the interest of economy, clearing operations on large reservoirs usually extend through one or more growing seasons and considerable regrowth occurs during the intervening period between initial clearing and impoundage. The final conditioning operation consists of removal of all such regrowth from the zone of fluctuation prior to impoundage.

BASIC CLEARING LINE

Selection of the basic clearing line is of primary importance in reservoir preparation for it will establish the upper limit of the zone in which satisfactory mosquito control can be achieved through the use of water level management, shore line maintenance, and the supplemental use of larvicides. Where malaria prevention is sought through mosquito control, the clearing line should be set at an elevation which will not be exceeded by the water level for periods of time longer than 7 to 10 days during the middle portion of the mosquito-breeding season or longer than 10 to 14 days during the beginning and ending of the mosquito season. Where special ecological circumstances, such as climate or altitude, prolong larval development, the permissible period of the water elevation exceeding the basic clearing line may be extended.

Terms relating to certain pool elevations and zones of interest in mosquito control as used in this manual are defined as follows: (See fig. 50, ch. V.)

(2) *Maximum "mosquito-control" elevation.* This is usually the of the gates or spillway or the maximum water level.

(2) *Maximum "mosquito-control" elevation.* This is usually the normal maximum summer water level or the elevation of the basic clearing line below which antilarval methods are usually effective.

(3) *Minimum "mosquito-control" elevation.* This is the low water elevation usually reached during the mosquito season.

(4) *"Mosquito-control" fluctuation zone.* The zone between the maximum and minimum "mosquito-control" elevations.

(5) *"Mosquito-control" surcharge zone.* This is the zone between the maximum "mosquito-control" elevation and the maximum pool elevation. This zone is utilized in mosquito-control operations for stranding drift and flotage above the clearing line.

From the malaria control standpoint, impoundages can be classified into three general types:

(1) Reservoirs having relatively little variation of pool level, where filling to the spillway crest and retention within a narrow zone (usually 2 to 6 feet) of fluctuation below this level is scheduled every year during the mosquito-breeding season.

(2) Reservoirs of wide pool level variation (usually 10 feet or more) where complete or nearly complete filling to the normal maximum summer elevation (maximum "mosquito-control" elevation) is expected nearly every year during the mosquito-breeding season.

(3) Reservoirs of wide pool level variation where complete filling to the maximum pool elevation during the mosquito-breeding season is expected only at rare or infrequent intervals of once in 10 to 25 or more years, and where the variation in peak water levels expected each year covers a wide range.

Typical of the first type of reservoirs are run-of-river, navigation, and recreation projects. Typical of the second type are hydroelectric, water supply, and multipurpose power-flood control impoundages. The selection of a basic clearing line or maximum "mosquito-control" elevation for these two types of reservoirs is relatively simple. It usually coincides with the normal maximum summer operating level anticipated in the design of the dam on the basis of the primary objective of the project.

A surcharge of flood zone is frequently incorporated into these types of reservoirs. If use of this zone is not scheduled for periods of time longer than 7 to 10 days during the mosquito-breeding season, adjustment of the basic clearing line above the normal maximum summer operating level is unnecessary. However, such adjustment should be considered if use of the surcharge zone for more prolonged periods during the mosquito-breeding season is expected more often than once in 5 years.

In the first two types of reservoirs, malaria prevention should be sought primarily through antilarval measures, utilizing reservoir preparation, shore line improvement and maintenance, water level management, and larviciding as required. During emergency situations such as the flooding of the uncleared surcharge zone for a period sufficiently long to cause significant production of mosquitoes, appropriate supplementary measures such as increased use of larviciding and house-spraying should be employed.

The third type of reservoir, typified by the single purpose flood control project, offers a more difficult and complex problem of selecting a basic clearing line since upon this selection depends the extent to which the basic antilarval approach would be employed in contradistinction to the use of alternative antimalaria measures.

It is obviously impractical to attempt mosquito control on this type of project through clearing, periodic growth removal, and larviciding in an upper portion of the reservoir which is not flooded more often than once in 10 to 25 years or more. The clearing and maintenance of this zone would usually involve an expenditure which could not be justified in terms of effectiveness. The problem therefore resolves itself into one of establishing the basic clearing line at an elevation below which the basic antilarval approach to malaria control is feasible. This decision must be based on epidemiological, biological, and engineering data developed for the individual project. The protection offered by the basic antilarval measures would be supplemented as necessary through use of alternative measures such as increased use of larvicides, mosquito-proofing, house-spraying, or restriction of land use to daytime occupancy.

The selection of a basic clearing line for reservoirs of this type should, therefore, be preceded by (1) a study of the probable frequency and duration of flooding certain elevations during the mosquito season and selection of tentative clearing lines and (2) their evaluation in terms of probable effectiveness, economy, feasibility, and appropriateness of applying alternative control methods. The beneficial effect of flooding the cleared zone below the basic clearing line in controlling marginal growth should be weighed against the

increased mosquito-breeding potentialities which would result from frequent and prolonged flooding above this line. In some instances, an upward adjustment of the basic clearing line might be made in specific sections of the reservoir to provide additional protection for areas of high population density or for recreation areas. In other instances, a downward adjustment might be made where no habitations exist or where land-use restriction is used. Generally, reservoirs of this type should be cleared to an elevation which would not be exceeded more frequently than once in about every 3 to 5 years during the mosquito-breeding season.

The advice and approval of the official health agency having jurisdiction should always be sought in reaching a decision as to adjustments between the basic antilarval approach and alternative approaches to malaria control.

To assist in the selection of the basic clearing line for storage reservoirs (type (3) p. 37), a method of computing the probable pool elevations and their frequency (and duration) of occurrence is illustrated in appendix B.

Such hydraulic studies when correlated with biological and epidemiological considerations, such as marginal vegetation, anopheline breeding potentials, population densities, malaria prevalence rates, and economic factors, will be most useful in establishing a basic clearing line. Such information is also of value in preparing estimates of clearing, shore line maintenance, larviciding, and other control measures required.

The basic clearing line as discussed for various types of reservoirs usually defines reservoir clearing and growth removal operations except where special alterations are needed for varying shore line conditions. It may also be used as the base line for water level management schedules. In some instances, it may be necessary to adjust the basic clearing line in the upper regions of long reservoirs to conform to the backwater curve for the average summer stream flow. Other clearing practices such as removing brush, logs, and debris for certain distances beyond the clearing line, clearing the upper ends of bights and indentations to provide space for piling and burning drift, and other special requirements to be subsequently discussed in this chapter, are all referred to the basic clearing line.

The establishment of the basic clearing line and computations regarding the frequency and duration of flooding and hydraulic operations of the reservoir as related to malaria control should be carried out with the cooperation and assistance of the hydraulic and planning engineers concerned with the design and operation of the project.

CLEARING

To provide optimum marginal conditions for all types of shore line in a reservoir, it is necessary to adjust marginal clearing practices to meet specific requirements of each type of shore line encountered. Just as reservoirs vary in type, size, and character from deep mountain storage reservoirs with steep shore lines (fig. 8) to main river, multipurpose reservoirs with extensive flood plain shallows and wide expanses of open water (fig. 9), sections of a given reservoir also vary from mile to mile according to topography, ex-

FIGURE 8.—Steep, rugged topography typical of storage reservoirs. (Note clearing prior to impoundage.) Norris Reservoir, Tenn.

posure to wave action, type of soil, and character of natural growth.

After the basic clearing line and water level management schedules have been determined, detailed specifications for preparation of the reservoir should be prepared. These specifications should be based on the impounded water regulations (appendix A) of the State or States concerned, and should define the marginal treatment for each type of shore line and the limits of marginal drainage. (A graphic summary of the clearing and drainage specifications used in the preparation of Kentucky Reservoir on the Tennessee River is shown in figure 10.) Items which should be considered in the preparation of a reservoir are discussed in the following paragraphs.

General clearing

Proper reservoir preparation requires that all trees, brush, logs, or other materials below the basic clearing line which might float or

collect flotage and drift when water is impounded be cut, piled, and burned or otherwise disposed of. (Timber may be left standing in deep reservoirs where it will be completely submerged at maximum draw-down. Timber rooted below this elevation but which extends above it may be felled and tied down in lieu of disposal.) All underbrush, dead trees, logs, drift, debris, and trees leaning so that branches would touch the water surface at the normal pool elevation, should be removed from the area above the basic clearing contour for a landward distance of 10 to 15 feet as measured along the

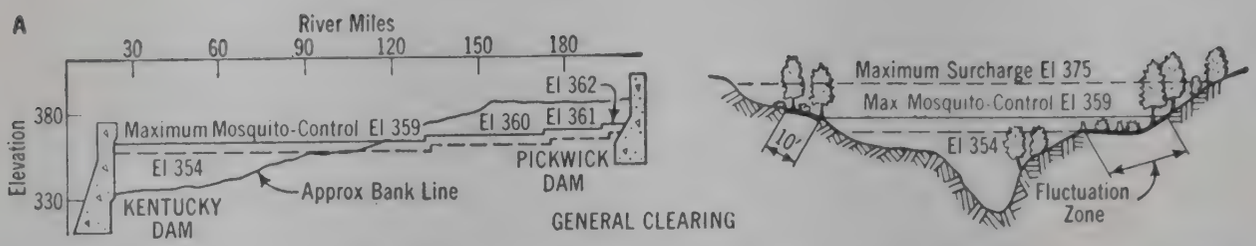
FIGURE 9.—Broad, flat topography typical of a main-river reservoir. Wheeler Reservoir, Ala.

slope of the ground, except along cliffs or where the shore line is likely to erode. In order to eliminate projections which would collect flotage and interfere with boat and maintenance operations, and to reduce sprouting, all trees, shrubs, and stumps in the "mosquito-control" fluctuation zone should be cut as close to the ground as practical.

All similar material which would project above the minimum "mosquito-control" elevation should be cut at least 1 foot below that elevation. Log and brush piles should not be left unburned above the clearing line as such debris constitutes a fire-hazard and potential source of drift in the reservoir after impoundage.

Clearing on cliffs

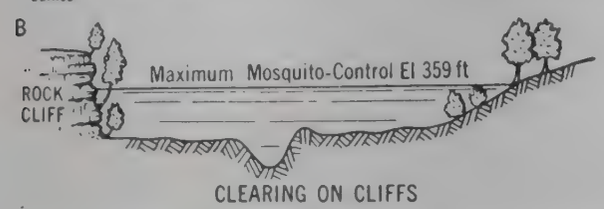
Where the clearing line is along a sheer cliff or other precipitous shore line and where it would be difficult for workmen to carry out



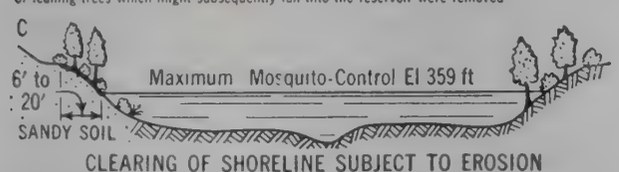
All trees, brush, logs, or other material in the reservoir, its branches, bights, and indentations as defined by the 359' contour (adjusted to allow for the effect of backwater) which might float or collect flotage or drift were cut, piled, and burned

Along the shoreline above the 359' contour for a landward distance of 10 feet measured along the slope of the ground all underbrush, dead trees, undesirable species, logs, drift, and debris were burned, except as modified in B and C

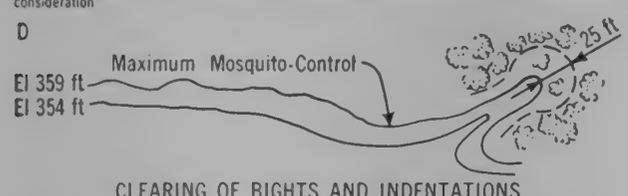
All trees, brush, stumps, posts, and other woody projections between the 354' and the 359' contour were cut as close to the ground as practicable All similar material projecting above El 354 was cut at least one foot below this elevation



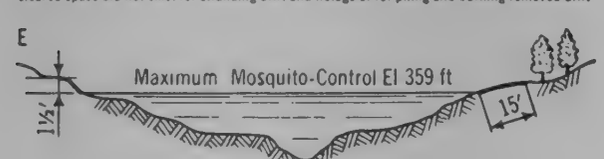
On sheer cliffs the clearing was stopped at the 359' contour Above this contour only the brush and trees were removed which would hang down and touch the water surface at El 359 Dead, diseased, or leaning trees which might subsequently fall into the reservoir were removed



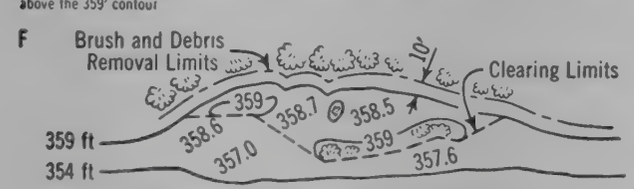
On the shoreline exposed to the main body of the reservoir and which was of a soil likely to be quickly eroded by wave action, complete removal of trees and brush was extended horizontally from 6 to 20 feet, depending upon the degree of erosion expected beyond the 359' contour The distance cleared above the 359' contour was determined by field inspection of the shoreline under consideration



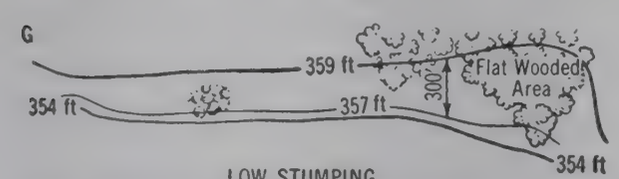
The upper ends of bights and indentations along the main body of the reservoir which were likely to collect drift and flotage were cleared for a distance of 25 feet from the 359' contour where sufficient cleared space did not exist for stranding drift and flotage or for piling and burning removed drift



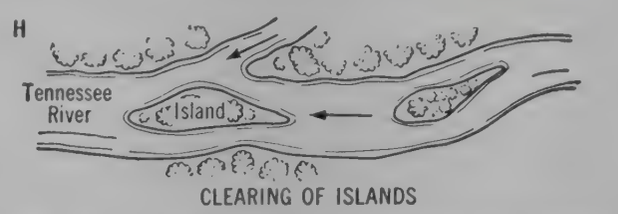
In certain areas, particularly in the lower reservoir all trees encountered including the few which might be tolerant to inundation were cleared for a horizontal distance of 15 feet landward as measured along the slope of the ground or for a horizontal distance equivalent to 1⅓ feet vertically above the 359' contour



In certain flat areas of the margins of the reservoir where trees tolerant to flooding existed complete clearing was extended only to where the 359' contour was first encountered Brush and debris were removed from this line landward to a line 10 feet beyond where the 359' contour was last encountered



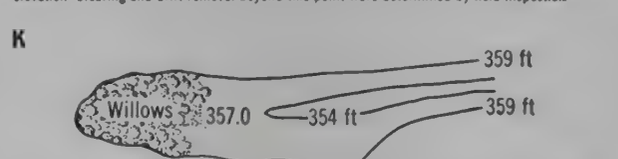
In certain flat areas between El 359 and 357 all trees underbrush, snags, etc were cut so that the height of the stumps did not exceed four inches These areas were determined from field inspections of each site Willow stumps were cut flush with the ground between the 359' and 354' contours



Islands created in the reservoir which were likely to erode were completely cleared The islands to be cleared were determined by field inspections.

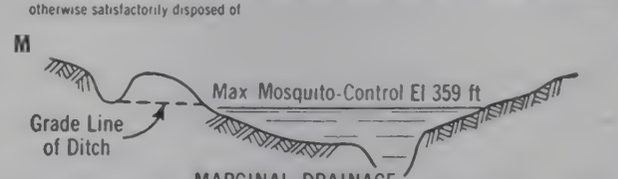
In areas where airplane application of larvicides was anticipated trees standing immediately above the 359' contour were removed where they existed as an obstacle to effective airplane flight

All clearing was stopped along the margins of the reservoir and its tributaries where the 359' contour, adjusted for backwater, was confined to the bank and intersected the average summertime water elevation Clearing and drift removal beyond this point were determined by field inspection



Willow stumps were cut flush with the ground in the fluctuation zone as defined by the 359' and 354' contour to facilitate killing the stumps by submergence Arboricide was applied to willow stumps in selected areas Provision was made for the eradication of selected obnoxious species of aquatic growth

All coppice, weeds, vines, and other herbaceous growth between the 354' and 359' contours and in the 10-foot zone above the 359' contour were cut and burned All coppice and unusually high herbaceous vegetation below the 354' contour which would extend above the 355' contour were burned otherwise satisfactorily disposed of



All depressions lying between the 354' and 375' contours which would become filled at maximum water level and form isolated pools when the water was lowered were connected with the main body of the reservoir by installation of suitable drains or ditches wherever practicable

FIGURE 10.—Graphic summary of clearing and drainage specifications for Kentucky Reservoir on the Tennessee River.

the operations, clearing is generally stopped at the basic clearing line. Above this line it is practical to remove only the brush and trees which would hang down and touch the water surface, and the dead, diseased, or leaning trees which might subsequently fall into the reservoir.

In most cases the shore line coming under this classification is open and would be exposed to wave action after impoundage and is therefore of secondary importance in mosquito control.

Clearing on shore lines subject to erosion

Experience has demonstrated that wave action will result in erosion of steep banks of loose soil where exposed to a considerable expanse of water, regardless of whether or not the shore is wooded. In such areas the upper limit of clearing should be extended above the basic clearing line a horizontal distance of 6 to 20 feet, or farther when considered advisable. In each case the distance to be cleared above the basic clearing contour would be determined by the degree of erosion expected, which in turn depends upon the exposure to wave action, the slope of the banks, and the character of the soil. An empirical formula which may be used in the absence of any better data to estimate the distance required for erosion clearing is as follows:

$$D = C \times \frac{0.1\sqrt{r}}{\cos\Phi}$$

Where, D = Extension of clearing in feet measured along the ground surface

r = Reach of reservoir over which wind can sweep in feet

Φ = Slope of shore line in degrees

C = Soil character coefficient

C = 0.5 thin mantle of soil underlain by rock
1.0 firm clay soil
1.5 average gravelly loam
2.0 loose sandy loam
2.5 very sandy soil

Additional clearing for erosion along an exposed section of a reservoir shore line is illustrated in figure 11.

Clearing of bights and indentations

On an impoundment the greatest accumulations of drift usually occur in the shallow bights and indentations along the main body of the reservoir (fig. 12) . Removal of this drift is essential to mosquito

FIGURE 11.—Exposed section of a shore line where clearing was extended above and beyond the basic clearing line (El. 359 ft.) in anticipation of bank erosion.

control, and is usually accomplished by piling and burning such accumulations at the heads of the bights and indentations.

Where accumulations of drift are expected to occur, clearing should be extended a distance of 25 feet from the basic clearing

FIGURE 12.—Accumulation of drift in an indentation where clearing was not carried beyond the basic clearing contour to provide space for stranding drift, or for piling or burning it.

contour to provide space for stranding drift and flotage, and for piling and burning the removed drift (fig. 13).

Selective clearing

"Selective clearing" is the removal of trees along the margins of a lake which are intolerant to flooding of their root systems for even a few weeks during the growing season. When such trees are inundated, they are usually killed during the first few years of impoundage, and subsequently find their way into the lake as drift and flotage.

Determination of the line or contour to which selective clearing should be carried will depend on the tolerance of the various species of trees present (see appendix B) and the duration, frequency, and

FIGURE 13.—An indentation where provision was made for stranding, piling, and burning of drift.

season of flooding. This line may be established in a manner similar to that previously described for the establishment of the basic clearing line.

Observations on reservoirs with a more or less normal maximum summer pool have indicated that most of the trees killed along the margins by "drowning out" were either less than 1 1/2 feet vertically above or 15 feet horizontally landward from the maximum summer pool contour. Intolerant trees within these limits should in the interest of economy be removed prior to impoundment.

Selective clearing is indicated only where intolerant trees are encountered, and where erosion clearing and removal of trees at

heads of bights do not extend to or beyond the limits established for selective clearing. In storage, and particularly in flood control reservoirs, more extensive use of selective clearing above the basic clearing line may be indicated.

Clearing in extremely flat areas

In extremely flat areas it is difficult to define an exact location of the basic clearing contour, and in such areas where the trees are relatively tolerant to flooding, complete clearing may in some instances be stopped where the contour is first encountered. However, undergrowth and debris should be removed from the point where clearing is stopped to a distance of 10 feet landward from where the clearing contour is last encountered. The trees left standing will provide shade which will inhibit the growth of underbrush and other objectionable vegetation. In general, as the water in such areas is shallow during the early part of the mosquito-breeding season, the uncleared area is dewatered soon after recession is begun. Some savings may result if clearing is stopped where the contour is first encountered, but this practice must be limited to very special situations where proper consideration has been given to topography, anticipated water elevations, and the ability of trees to withstand submergence of their root systems during the spring.

Low-stumping

To permit the use of mechanical equipment in annual fall shoreline maintenance operations after impoundage, stumps in certain flat areas should be cut at a height not to exceed 4 inches and preferably flush with the ground. Since stumps cut low are submerged for a longer period in the spring, low-stumping will help to prevent their sprouting. Low-stumping will also permit the use of power rakes for piling felled timber. In the selection of areas for low-stumping, consideration should be given to the topography, size and location of area, and the size and type of timber. In general, large trees which are costly to cut low in this manner are excepted. It is also impractical in most areas to low-stump trees with swollen butts such as cypress and tupelo gum. Low-stumping is usually confined to the upper portion of the "mosquito-control" zone in anticipated problem areas. Figure 14 illustrates a flat problem area where the trees were not cut low.

Clearing of islands

Impoundage of a reservoir frequently results in the formation of a number of small narrow islands in the main body of the lake. Where such islands are composed of silt or similar material and

FIGURE 14.—Flat, marginal area where the stumps were cut high. The stumps were fortunately killed by submergence during the first summer following impoundage but remained as obstacles to shore line maintenance operations.

exposed to wave action, a part or all of the timber as indicated should be removed to prevent its falling into the lake as a result of erosion.

Clearing for airplane larviciding

In areas where airplane application of larvicides is anticipated after impoundage, single trees and small groups of trees standing immediately above the clearing line should be removed where they might offer a distinct obstacle to airplane operations. This does not usually involve much additional clearing, and it is more economical to remove such trees along with the original clearing than to postpone such work until after impoundage.

Upper limit of clearing

A. quadrimaculatus production does not normally occur along the banks of larger streams under natural conditions and impoundage does not materially change these conditions above the point where the surface of the lake intersects the normal summertime elevation of the stream. For this reason, clearing operations are generally stopped at this point on the main river and tributary creek channels. However, it is good practice to continue upstream for a distance, removing any fallen trees, logs, limbs, or debris which might later be carried into the reservoir. The upper limit of clearing under such conditions is best established by survey and field inspection.

Burning

Final disposal of timber and brush from basin clearing operations is usually accomplished by burning. Such burning should be planned and controlled in a manner which will prevent or limit injury to trees that are left standing around the margin of the lake. Trees damaged by burning may subsequently disintegrate and find their way into the reservoir creating additional drift and flotage.

Willow stump poisoning and aquatic growth control

Willow trees, being semiaquatic, thrive in the zone of fluctuation, and, due to their characteristic prolific sprouting, create a favorable environment for anopheline production. To limit sprouting, willows in the "mosquito-control" fluctuation zone should be cut flush with the ground and treated with fuel oil or some other suitable arboricide. Colonies of objectionable aquatic plants, such as lotus and alligator weed, either in the "mosquito-control" fluctuation zone or in deeper portions of the reservoir, may spread and develop into a problem after impoundage and should be eradicated by mechanical or chemical means as a preimpoundage operation. (See "Aquatic Growth Control," ch. VI.)

CLEARING OPERATIONS

Determination of the specific clearing requirements for the various types of shore line which will be encountered requires a thorough field reconnaissance of the proposed reservoir. It is often convenient and advantageous to conduct this survey at the time the basic clearing contour is being staked in the field. Competent personnel can, by studying the character of the soil, the exposure to wave action, the slope, the type of cover, and other pertinent factors, indicate on appropriate field maps the type of marginal clearing required for malaria control along the various sections of shore line. These shore line survey maps can later be used to guide clearance forces in the application of special types of marginal clearing.

The upper limit of clearing may be readily established in the field by marking the trees with a color paint. In areas where special clearing is required, such as low-stumping or flush-cutting willows, the lower limit may be marked on standing trees by suitable colors which will serve as a "code" to clearing crews. The clearing line should be marked well ahead of the clearing operations, and frequent inspections of these operations should be made for the purpose of obtaining practical adherence to the clearing specifications.

Clearing is usually the responsibility of construction forces; however, an understanding of general practices employed in the

clearing of large reservoir basins is helpful to those responsible for malaria control. For this reason a general description of clearing methods and practices in use at this time is included in the following paragraphs.

Some factors which must be considered in the planning and scheduling of clearing operations are closure date of the dam, total acres of clearing, types of clearing, drainage requirements, and the number of clearing units required to complete the work in the allotted time. In the detailed planning of clearing operations it is usually desirable through field reconnaissance to divide the clearing into a number of classifications, such as miles of bank clearing, acres of lowland clearing that can best be done during summer months, areas requiring drainage prior to clearing, upland clearing that can be done during winter months, areas suitable for cutting and power raking, deep areas where timber can be left standing, and marginal flats that should be scheduled for clearing just before impoundage to reduce the amount of regrowth requiring removal in the final conditioning operations. From this information, the personnel and number and types of tools and equipment that will be required can be determined and a preliminary schedule established. Drainage required to facilitate clearing should be correlated with marginal drainage for mosquito control. Additional drainage to facilitate clearing is usually necessary only below the minimum "mosquito-control" elevation. Where clearing is scheduled ahead of purchase of the land, temporary clearance permits must be obtained from the landowners. Whenever growing crops are damaged during the clearing operations, damage claims should be settled promptly in order to help maintain satisfactory public relations.

In general, there are five types of clearing as considered from the operations standpoint: (1) "regular clearing" in which timber is cut and piled by hand and teams; (2) "cutting and machine raking" in which felled timber is piled by power rakes; (3) "bank clearing" where timber is felled into streams and pulled out onto the banks by teams and machines; (4) "cutting and tying down;" and (5) "rebrushing," a term commonly used to refer to the final conditioning of the "mosquito-control" fluctuation zone.

An example of a procedure which may be followed on regular clearing is described as follows: A bush-hook crew is first sent through the tract of timber to cut and pile the brush and undergrowth. An ax crew follows to cut small trees which can be felled with a few strokes. Then, a light-saw crew goes through the tract to fell the smaller trees. A heavy-saw crew then fells the large trees.

FIGURE 15.—Logs and brush cut and piled for drying preparatory to burning.

Limbing of trees goes forward as the timber is cut into convenient lengths of about 12 to 14 feet. Brush and logs to be burned are piled separately with merchantable timber logs being left on the ground. Teams are ordinarily used in grouping and piling logs. For bes results in burning, the larger logs are placed on the bottom of the piles and the piles fired from the top with progressive burning to the ground (fig. 15). This clearing procedure, which until recent years was the principal method used, is still employed in areas where machine operations are not feasible because of either the

FIGURE 16.—Timber rake for windrowing felled trees without conditioning.

FIGURE 17.—Power rake pushing brush and logs into a windrow.

small quantity of work involved or unsuitable ground conditions.

In the past few years a "timber rake" has been developed for piling felled timber and brush in large scale clearing operations. This timber rake, shown in figure 16, consists of a bulldozer with a modified blade having two slides underneath the ends to hold the blade at the proper working elevation and provide clearance of stumps up to 6 inches high, and several flexible prongs or teeth hung on the blade for lifting and pushing the logs and brush.

These machines may be used singly, in pairs, or, in some cases,

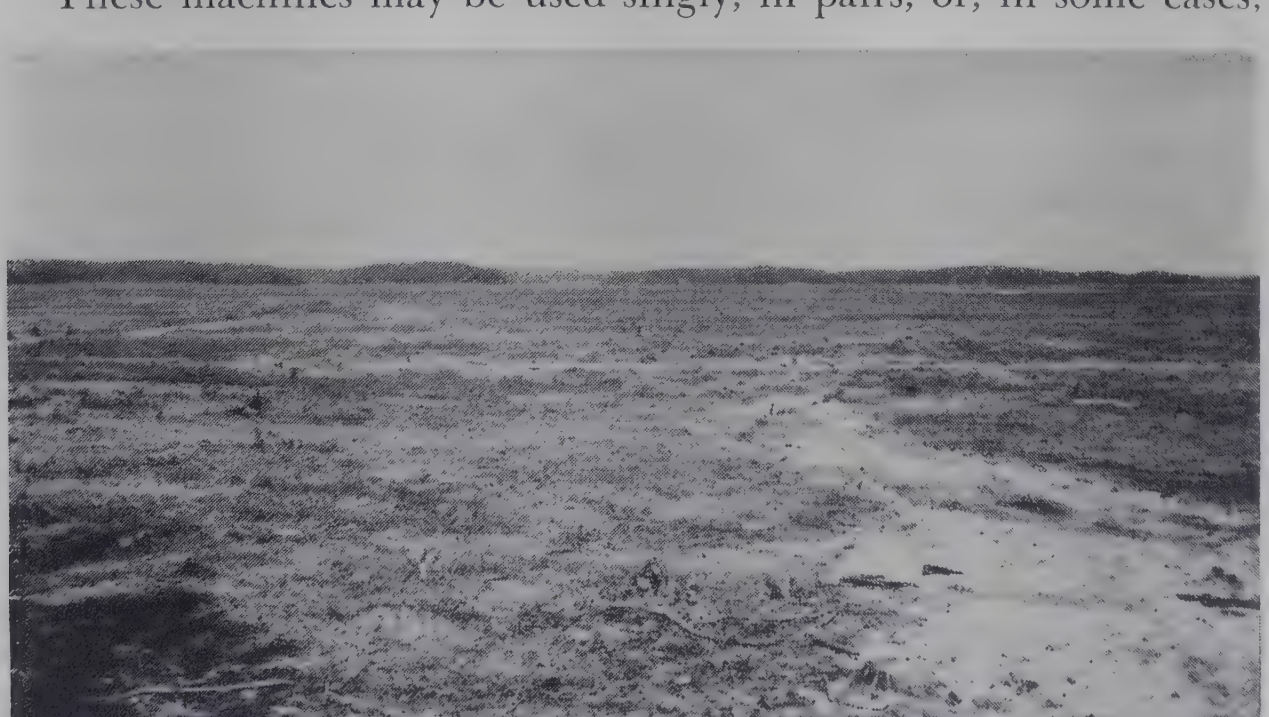


FIGURE 18.—Flat area after completion of clearing and burning. Trees in this area were low-stumped.

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FIGURE 19.—Bank clearing showing operation of specially equipped tractor with side winch, A-frame, and stiff legs. (Timber in background was pushed into windrows by a power rake.)

three machines may operate together. In areas where power rakes are employed, the timber and brush are felled, large trees are cut into two or three sections, and large branches are severed from the trunks to facilitate compaction. No other manual work is required. The timber may be allowed to dry either before raking or afterwards, depending on the requirements of the clearing schedule and ground conditions at the time of cutting. As shown in figure 17, the power rake can push the felled timber and brush into compact windrows by working alternately on each side of the pile. The sweeping action of the brush as it is pushed along serves to give an exceptionally clean job. The burning operation is initiated after thorough drying. Smaller power rakes may be used for pushing the last burning chunks together for complete disposal. A cleared area after the timber has been cut (low), piled with a power rake, and burned is shown in figure 18.

When clearing banks of streams, it is frequently impractical to prevent the larger leaning trees rooted in the banks from falling into the water when cut. Trees which have been felled into water may be dragged to the top of the bank for piling and burning with teams, tractors with a tail-winch, or a special bank machine (fig. 19).

This bank machine consists of a tractor with a side winch, short boom or A-frame, and a stiff leg, which is lifted into a vertical position when the machine is traveling. A crew of five or six men is usually necessary with this machine to unreel, tie, and free the

cable when removing trees from a stream. The machine is most useful where most of the trees are too large for pulling with a tractor without cutting into sections. Along the banks of some streams navigational interests may require that the trees be cut level with the ground and that the edges of the stumps be beveled.

In mountain storage reservoirs it is sometimes feasible in the deeper portions below the maximum draw-down elevation to cut and wire timber down in lieu of disposal by burning. Those trees which extend above the draw-down elevation are cut, and the felled trees, including in some cases timber pulled from the upper part of steep banks, are fastened securely to well-anchored stumps or boulders by means of heavy wire. This will prevent the timber from floating, and the trees will eventually become waterlogged and remain permanently submerged. This method should not be used where corrosion is liable to cause failure of the wire in the interval before impoundment or before the timber becomes waterlogged.

The shortage of manpower during the war accelerated the development and increased the use of power saws in clearing operations. Chain-type saws, either electric or gasoline driven, such as those illustrated in figures 20 and 21, will probably have widespread use in future clearing operations. These saws may also be used for flush-cutting high stumps to facilitate shore line maintenance operations (see fig. 70).

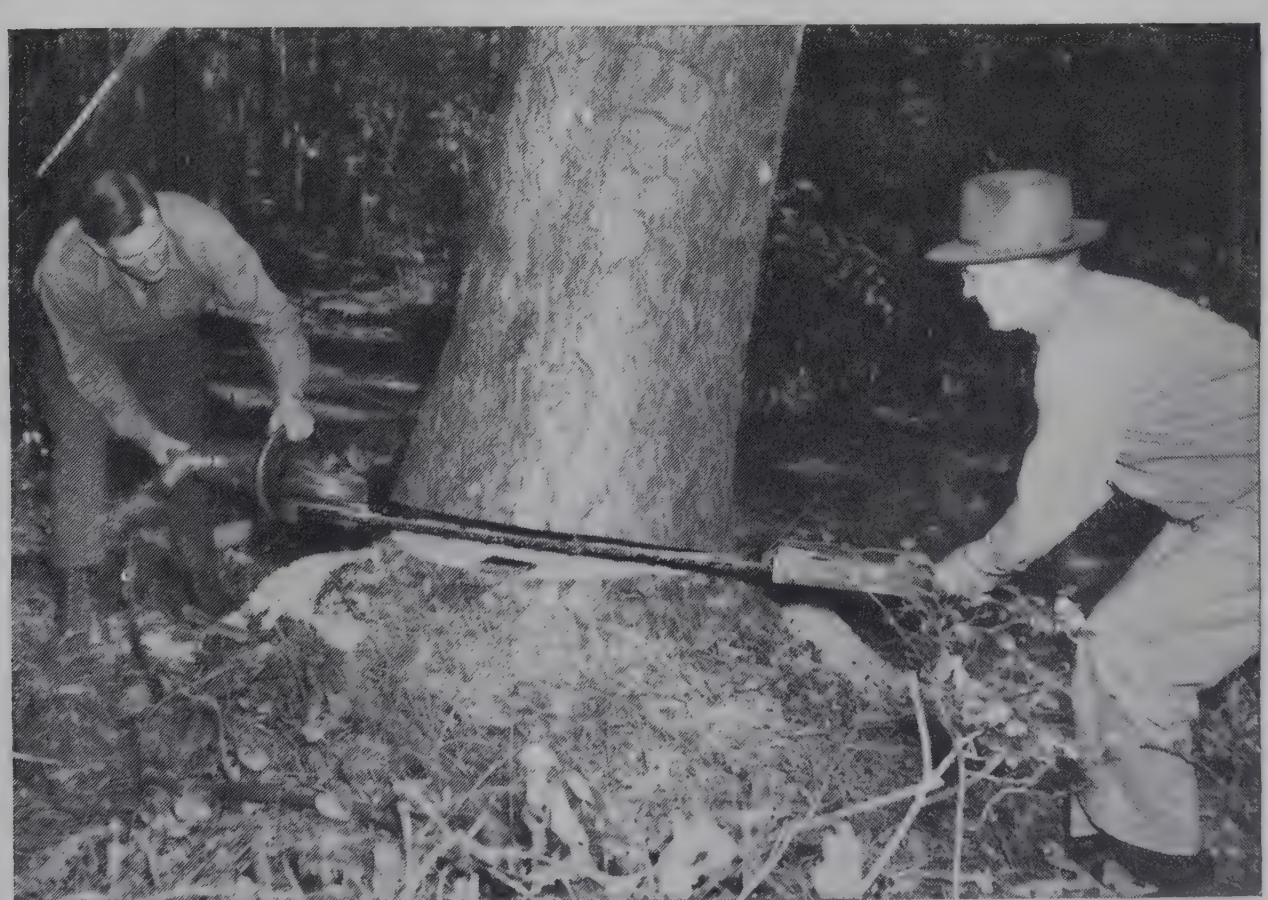

FIGURE 20.—Electric driven chain-type power saw for felling timber.

Operational figures based upon the experience of the Tennessee Valley Authority in clearing 182,000 acres of timber for reservoir preparation are offered below as a guide for estimating the relative labor requirements for several types of clearing.

Type of clearing or operation	*Man days per acre*
Regular clearing as distinguished from bank clearing	16.6
Bank clearing with piling by hand	22.5
Felling timber and brush in flat areas for piling by power rake	8.0
Felling timber and brush on banks for piling by power rake	15.0
Felling timber in deep reservoirs in preparation for wiring down	2.7
Wiring down felled timber in deep reservoirs	6.0
Burning piled timber and brush	2.0—3.0
Piling felled timber and brush with power rake (Machine days per acre)	0.1—0.2

(Mechanical saws were not used in the above clearing operations.)

MARGINAL DRAINAGE

The objective of marginal drainage is to provide complete drainage or connection with the main lake of all depressions, swamps, and marsh areas in the "mosquito-control" fluctuation zone which would exist as a mosquito problem after impoundage (fig. 22). Experience on storage or flood control reservoirs (where the basic clearing line is often set below the maximum or spillway elevation) has in many instances indicated the advisability of providing drainage of all lateral ponds up to the spillway crest.

Drainage should be designed and constructed so as to minimize annual ditch maintenance as far as possible and, where practical, should provide an entrance for mosquito control boats. Provision

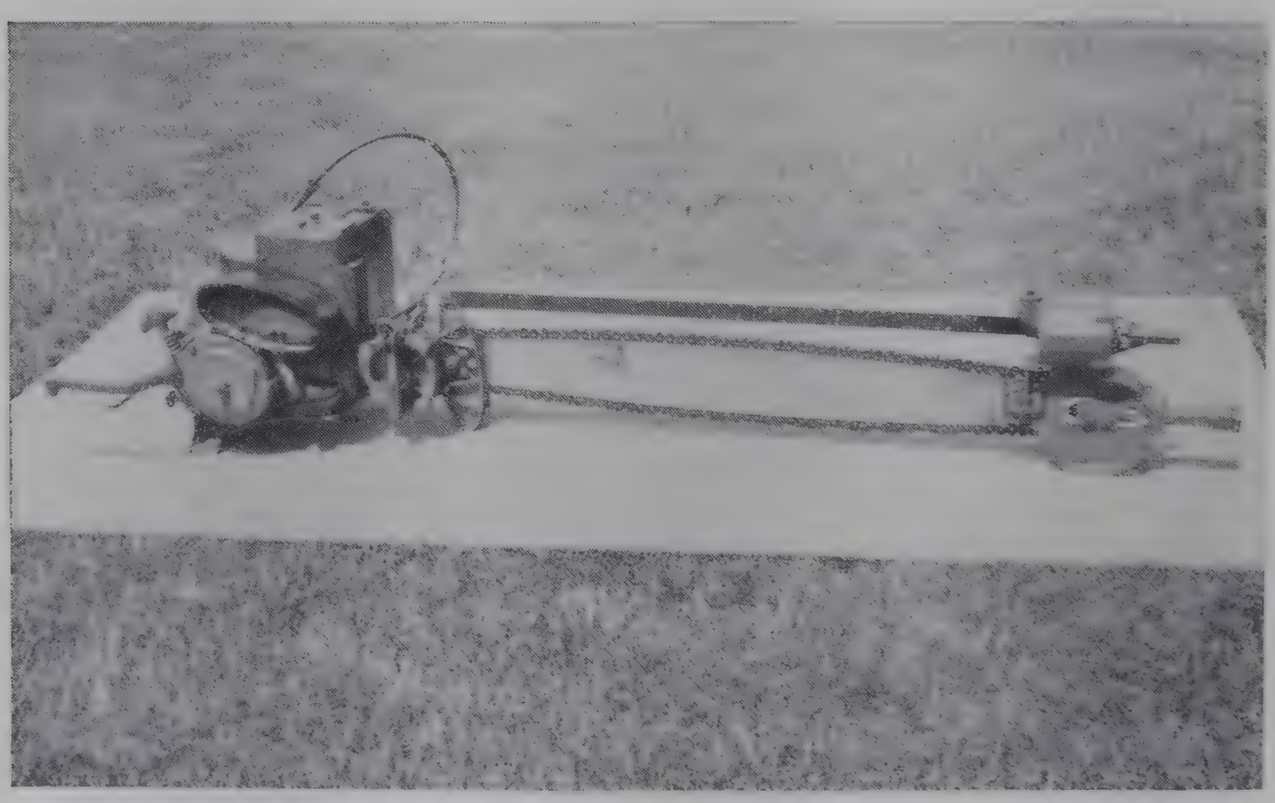

FIGURE 21.—Gasoline driven chain-type power saw for felling timber.

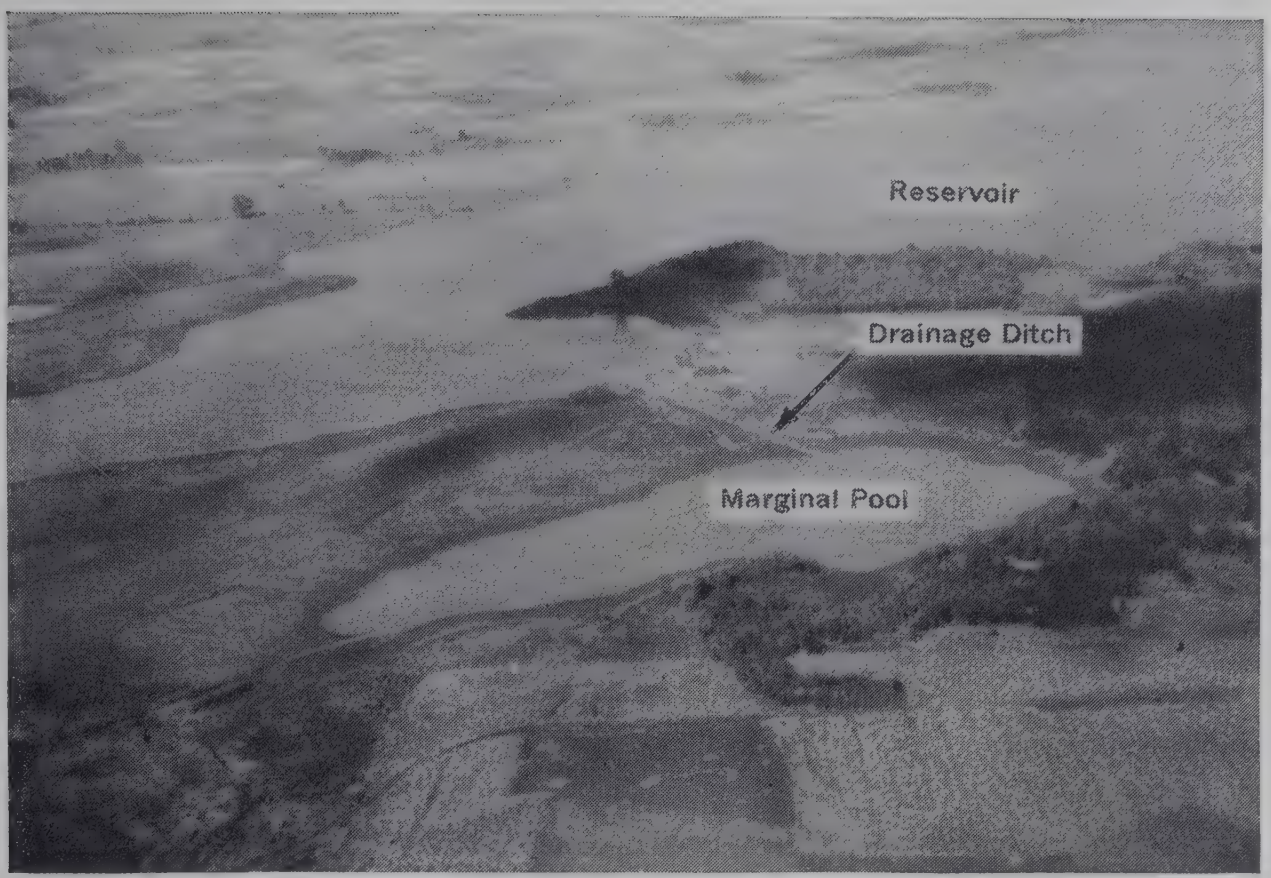

FIGURE 22.—Aerial view of a marginal ditch connecting a marginal pool with the main body of the reservoir. Wheeler Reservoir, Tennessee River.

should also be made for the removal of logs, drift, and other debris occurring in natural drains and existing ditches where such work is indicated for adequate mosquito control drainage.

Drainage plans and surveys

A complete reconnaissance survey of the entire reservoir should be made in order to study general drainage problems, and to locate areas between maximum and minimum pool elevation where drainage may be required for mosquito control. The best maps available should be used in this survey and tentative drainage areas spotted on them for later use in construction planning. A small hand level is useful in this work to establish the approximate elevation of tentative drainage areas. Accurate differential levels may be employed later to determine the elevation of swamps or ponds when there is some doubt of their lying in the fluctuation zone.

A preliminary survey to estimate the quantity of work and cost of construction is desirable. From such a survey it is possible to appraise the economic feasibility of a drainage project, as compared with possible alternative malaria control measures, such as partial drainage combined with larviciding, filling, larviciding alone, and in certain situations, mosquito-proofing. In certain areas, particularly those characterized by numerous lime sinks or irregular out-

crops of rock, the services of a competent geologist will be helpful in forecasting drainage characteristics after impoundage and the extent and type of rock excavation to be expected. A geologist may also provide helpful information where there is a possibility of obtaining vertical drainage of lime-sink depressions.

Drainage projects should be inspected at intervals during construction, as well as after completion, to insure that work is performed according to plan and that the purpose of the drainage has been accomplished.

Drainage operations and construction

Preimpoundage drainage operations are directed toward the construction of ditches required for fluctuation or complete drainage of major ponded areas or depressions. The need for minor drainage work can best be determined after impoundage and is often considered a part of the postimpoundage program. During reservoir preparation, major drainage ditches are usually constructed by draglines or other suitable excavating equipment. Hand ditching or slip scrapers may be more economical where the yardage involved is too small to justify moving a machine to the job. Ditching with dynamite may be indicated under special conditions, such as the provision of partial or complete drainage of a swamp area to facilitate right-of-way clearing for subsequent construction of a dragline ditch to proper section and grade.

Drainage practices used in general swamp or pond drainage are also applicable to marginal reservoir ditching. As far as is practical, ditches should follow natural low ground; side slopes should be flat enough to prevent sloughing; and the high point of the grade should be 1 to 2 feet lower than the area drained. Storm flows should be taken into consideration in the design of malaria control drainage ditches. Abrupt change in grade and alignment should be avoided. The section may vary with the depth of cut and the type of soil (table 3) but in general a section with side slopes of 1 on 1.5, and a bottom width of 4 feet, is satisfactory from both the construction and maintenance standpoint up to depths of 5 feet in the types of soil usually encountered in river flood plain areas. Flatter slopes may be used where loose materials are encountered, and steeper slopes where stiff clay or other stable soil exists. Vertical sides may be used where excavation is in rock. The bottom width should be increased to 6 feet where the ditch is to serve as a boat channel after impoundage. Open ditches are preferable except where special conditions require the use of a pipe, such as a deep cut in unstable material where maintenance after impoundage would be very difficult.

TABLE 3.—*Side slopes of earth ditches*[1]

Type of soil in which cut is made	Side slopes
Firm rock	1 on ¼
Fissured rock, more or less disintegrated rock, tough hardpan	1 on ½
Cemented gravel, stiff clay soils, ordinary hardpan	1 on ¾
Firm, gravelly, clay soil	1 on 1
Average loam or gravelly loam	1 on 1½
Loose, sandy loam	1 on 2
Very sandy soil	1 on 3

[1] Etcheverry, B. A., and Harding, S. T.: "Conveyance of Water" in *Irrigation Practice and Engineering*, 2nd edition, vol. 1, McGraw-Hill, 1933.

Ditch grades for drainage of marginal swamp and seepage areas usually vary from 0.05 percent in flat alluvial flood plain swamp areas up to 1.5 percent where this amount of grade is possible. Maximum grade for any soil should be less than that which will produce excessive velocities with undue scouring and pitting of the ditch. (See table 4.) Where a lateral ditch with a steeper grade enters a main drain, the first 50 to 100 feet of the lateral should have a flat grade to serve as a silt basin in order to minimize silting in the main ditch; in some instances masonry or concrete drops or chutes may be required. Where a natural drain enters a ditch above grade, a lateral inlet should be constructed, as described above, to prevent the creation of a waterfall effect with subsequent scouring of the bank and silting of the main ditch.

TABLE 4.—*Maximum Velocities Safe Against Erosion*[2]

Type of soil	Mean velocity in feet per second
Very fine loose sand	0.75– 1.00
Fine loose sand	1.00– 1.50
Coarse sand or light sandy soil	1.50– 2.00
Average sandy soil	2.00– 2.50
Sandy loam	2.50– 2.75
Average loam, alluvial soil, volcanic ash	2.75– 3.00
Firm loam, clay loam	3.00– 3.75
Stiff clay soil, ordinary gravel soil	4.00– 5.00
Coarse gravel, cobbles, shingles	5.00– 6.00
Conglomerates, cemented gravel, soft slate, tough hardpan, soft sedimentary rock	6.00– 8.00
Hard rock	10.00–15.00

[2] Etcheverry, B. A., and Harding, S. T.: "Conveyance of Water" in *Irrigation Practice and Engineering*, 2nd edition, vol. 1, McGraw-Hill, 1933.

The width of right-of-way required for construction depends upon the depth of cut, the ditch section, and the size of dragline and length of boom used for excavation. The minimum right-of-way width required for dragline construction is approximately 60 feet, and may be twice that where deep cuts necessitate piling spoil banks on both sides of the ditch. Construction slope stakes are sometimes set before right-of-way clearing is initiated to serve as a guide in minimizing

clearing required for construction purposes. Stakes disturbed by clearing and stump blasting operations may be reset as needed. A berm of at least 10 to 15 feet should be left between the ditch and the toe of the spoil bank. Timber cut for the construction right-of-way should be piled and burned where practical, but in swampy areas where burning is difficult or impossible it may be more economical to pile logs in windrows and cover them with waste dirt from the excavation. Stumps located in a ditch section can be removed by a special hook attached to the dragline bucket if first shattered by blasting.

One-half cubic yard draglines with 35-foot booms have been found to be particularly suitable for this type of drainage construction. They are large enough for efficient operation and yet small enough to be moved easily. This machine can travel and operate in swampy areas on mats made of small logs lashed together with cables. Two machines, one on each side of the ditch, may be used effectively on deep cuts of considerable length. Excavation is usually carried ½ to 1 foot below grade in swampy areas to allow for grade irregularities and muck that often flows back into the ditch. Skilled operators are necessary to secure a uniform section and grade as illustrated in figure 23. Frequent breaks should be left in the spoil banks to permit surface run-off into the ditch. Where the ditch traverses flat, shallow problem areas, the spoil banks should be leveled by a bulldozer or grader, as shown in figure 24, to minimize

FIGURE 23.—Dragline construction of a marginal drainage ditch.

the ponding of water behind the spoil banks and to facilitate future growth removal operations along the ditch banks. (See fig. 84.)

Where rock is encountered, blasting will be required except for some types of shale and boulder formations which frequently can be excavated by draglines.

Under average working conditions, a ½-cubic yard dragline will excavate 200 to 300 cubic yards per 8-hour day. Using this type of machine, several million cubic yards of earth were excavated for marginal mosquito control drainage ditches in the preparation of reservoirs in the Tennessee Valley, at an average cost of 21 cents per cubic yard, including materials, explosives, and right-of-way clearing above the reservoir clearing line. Excavation costs ranged from 9 to 15 cents per cubic yard, and clearing and grubbing averaged from 7 to 10 cents per cubic yard.

FINAL MARGINAL CONDITIONING OF MOSQUITO CONTROL ZONE

Clearing of large reservoirs usually requires more than one year; consequently, a heavy growth of coppice and herbaceous vegetation occurs during the growing seasons in the interval between clearing and impoundage. Failure to remove this regrowth prior to impoundage has in some instances rendered the effective control of mosquitoes impossible. It has been repeatedly demonstrated that the removal of such growth in the marginal zones of a reservoir prior to impoundage is essential to adequate mosquito control, and the

FIGURE 24.—Spoil banks of a marginal drainage ditch leveled to improve side drainage and to facilitate future shore line maintenance operations.

cost, which is not excessive, is more than offset by substantial reduction in antilarval maintenance operations during the early life of the reservoir.

The extent of the zone to be conditioned is determined by the water level management schedule and generally includes the marginal zone where seasonal recession is expected for mosquito control purposes. This final marginal conditioning should include cutting, burning, or otherwise disposing of coppice, weeds, vines, and other herbaceous growth in that portion of the "mosquito-control" fluctuation zone where regrowth will create a mosquito control problem and in the 15-foot zone above the basic clearing line. Coppice and unusually high herbaceous vegetation rooted below the minimum draw-down elevation and extending above that elevation

FIGURE 25.—Tractor mower with 6-foot blade for cutting light coppice and annual growth.

should be burned where sufficiently dense to be adequately consumed, or cut, piled, and burned where the quantity and character of the growth indicates economical removal in this manner. Small and scattered growth in this area should be cut but need not be piled or burned.

Rebrushing and final conditioning in the "mosquito-control" fluctuation zone should be scheduled in the period between the end of the plant growing season and the beginning of winter rains. Where the type of growth, weather, and ground conditions are suitable, firebreaks may be cut around the margin, and area burning

may be employed for the removal of regrowth. However, this method is usually limited to areas formerly in agricultural use. Cutting and piling by hand is usually the most effective method of disposing of heavy coppice. Small coppice and annual growth may be cut by mowers (fig. 25) and raked into windrows for burning. Either team or tractor mowers may be used where ground conditions are favorable. In areas of heavy growth of sprouts and vines hand labor may be reduced considerably by use of a heavy tractor-drawn "brushing" harrow, such as is shown in figure 26. Below the elevation of complete growth removal, growth projecting above this elevation should be topped, or cut so that it does not extend above this elevation. A straight, double-edged blade with a 4-foot, straight handle is well adapted to this operation and also for cutting overhanging limbs

FIGURE 26.—Tractor-drawn brushing harrow.

and other growth along ditch banks. Scattered toppings do not generally require piling and burning, but instead may be allowed to fall into the remaining growth. The condition of the fluctuation zone upon completion of final growth removal is illustrated in figure 27.

In the reservoirs of the Tennessee Valley Authority, 2 to 3 man-days per acre were required for the final growth removal operation in areas conditioned by hand. Team mowers averaged 3 to 4 acres per day and tractor units averaged 8 to 10 acres. Team rakes covered 10 to 12 acres per day. The brushing harrow covered approximately 8 acres per day. Approximately 1/4 man-day per acre was required for burning.

FIGURE 27.—Fluctuation zone after final conditioning.

CHANNEL MARKERS FOR MALARIA CONTROL BOATS

Efficient and safe operation of boats for inspection and application of larvicides in the shallow areas of a reservoir requires careful marking of boat channels by means of buoys or posts set before impoundage. Since this work is closely related to the clearing and drainage operations, it should be included as a part of the reservoir preparation program. Boat channels may be required for other purposes also, such as barge access to tie landings, recreation sites, and malaria control bases, and therefore, all of these needs should be considered and coordinated in the over-all channel marking program for the reservoir.

Standard navigational aids, such as buoys and day boards, are usually employed for marking the channels in the main reservoir and principal tributaries. Creek channels or navigable drainage ditches, which might provide access to the heads of embayments or other areas where inspectional or larvicidal malaria control work is anticipated, should be marked (fig. 28).

Posts, preferably cedar, locust, or other durable wood, may often be salvaged from clearing operations and used for this purpose. Posts of sufficient length to project 2 feet above the normal pool level are usually set on the left side of the channel (looking downstream) at intervals as necessary to define the safe channel. Some means of anchoring is necessary to hold wooden posts in place due to their inherent buoyancy. Posts which have been notched about 4 inches

FIGURE 28.—Channel markers for malaria control boats.

from the bottom are generally set about 3 feet in the ground, and the first 6 to 8 inches imbedded in a 1:3 cement-sand mixture. The remainder of the post hole may be filled with tightly tamped dirt. Painting the top 2 feet of the posts will help in identifying them as channel markers. In some situations post markers may conveniently be fastened to strategically located stumps. Iron pipes driven in place have been found to be more satisfactory where a marker is required on a sand or gravel bar.

IV. PERMANENT MARGINAL MEASURES

Permanent marginal measures embrace those measures which are directed toward eliminating the need for repetitive means of malaria control. These measures may include diking and dewatering, filling and deepening, lateral impoundage, land-use restriction, and shore line grazing. The application of diking and dewatering, and filling and deepening for malaria control employs the use of engineering works to eliminate shallow mosquito-breeding areas along the margins of a reservoir. Lateral impoundage and grazing are directed at reducing the conditions favorable for anopheline breeding. Land-use restriction does not affect mosquito production, but prevents malaria transmission by limiting the use of marginal lands within mosquito flight range of the reservoir to daytime occupancy during the malaria season.

PRIMARY CONSIDERATIONS

As indicated in the chapter on development of a malaria control program consideration of permanent marginal measures for specific areas of a reservoir should be based on the need for increasing the effectiveness of malaria control and reducing annual expenditures. An analysis of the conventional antilarval program, consisting of normal shore-line maintenance and larviciding, may be useful in making a comparison of relative costs. The application of shore line improvement should be explored during the early stages of planning the impounded water project, and a decision reached as to which measures are to be applied. Integration of malaria control features with the over-all planning and construction of a reservoir project may result in certain savings that would not be realized with conventional antilarval procedure.

A permanent marginal improvement program should be developed on a reservoir basis rather than for a particular area or section of the reservoir. Each potential problem area in a reservoir should be examined to determine the adaptability of such improvements for malaria control. A preliminary examination of the area will usually indicate the measure most applicable. This examination should include a study of the topography, extent of breeding area, drainage, soil conditions, population densities, and a consideration of water level schedules.

The planning of permanent marginal measures for an impounded water project should be preceded by the establishment of normal

water level schedules. The extent of the mosquito-breeding problem created by the invasion of marginal plants is governed largely by these schedules, and on a proposed impoundage the adopted schedule will serve in planning as a basis for forecasting the extent of marginal growth invasion. In run-of-river reservoirs of the Tennessee River the marginal growth invasion is limited to a maximum of approximately 2 feet where the summer draw-down does not exceed an average of 3 feet. It is to be noted, however, that this would be exceeded if a greater summer draw-down occurred, particularly during the early part of the growing season.

Engineering data and detailed maps are required in planning permanent control measures. Maps should indicate roads, streams, woods, property lines, houses, and topography of the reservoir area. Any existing anopheline mosquito-breeding areas should also be included. These maps should have accurate contours of significant water elevations as discussed in the chapter on water level management and have a scale of approximately 1 inch = 2,000 feet. Detailed topographic maps having scales of 1 inch = 500 feet or 1 inch = 200 feet are usually required for planning the engineering works. The engineering data should include operational features of the project, pertinent water level elevations, stream flow and accompanying backwater curves, together with topography and soil conditions of the region.

DIKING AND DEWATERING

Diking and dewatering has been widely used in agricultural drainage, and for flood protection with some incidental mosquito control benefits. This method has had only limited application in the past with mosquito control as the primary objective. However, it has recently been employed rather extensively for mosquito control in the Kentucky Reservoir by the Tennessee Valley Authority.

In general, diking and dewatering is most applicable to large shallow areas in the flood plain or tributaries of run-of-river reservoirs where the surface run-off is relatively small or can be reduced by diversion of the main drainage. An advantage of dewatering such areas is the reclamation of fertile land suitable for agricultural use in the area dewatered. Where this land is already in such use, the contiguous population is likely to be relatively high, thus making it especially important to provide adequate mosquito control. Figure 29 shows an extensive mosquito-breeding area in the flood plain of a main river reservoir which might well be eliminated by diking and dewatering. Figure 30 is an aerial view of a similar potential mosquito-breeding area which was eliminated by diking and dewatering.

FIGURE 29.—Impoundage in a typical river flood plain showing mosquito-breeding problem area—Wheeler Reservoir, Ala.

Prior to initiation of design, a thorough reconnaissance of the area should be made in order to ascertain the general layout of the dewatering project, including the tentative locations of dikes, spillways, interior drainage, and the pump station. In some instances it may be possible to divert drainage from the upland watershed

FIGURE 30.—Mosquito-breeding problem area eliminated by diking and dewatering. (Note reclamation of agricultural land within the project which otherwise would have been flooded)—Perryville, Kentucky Reservoir, Tenn.

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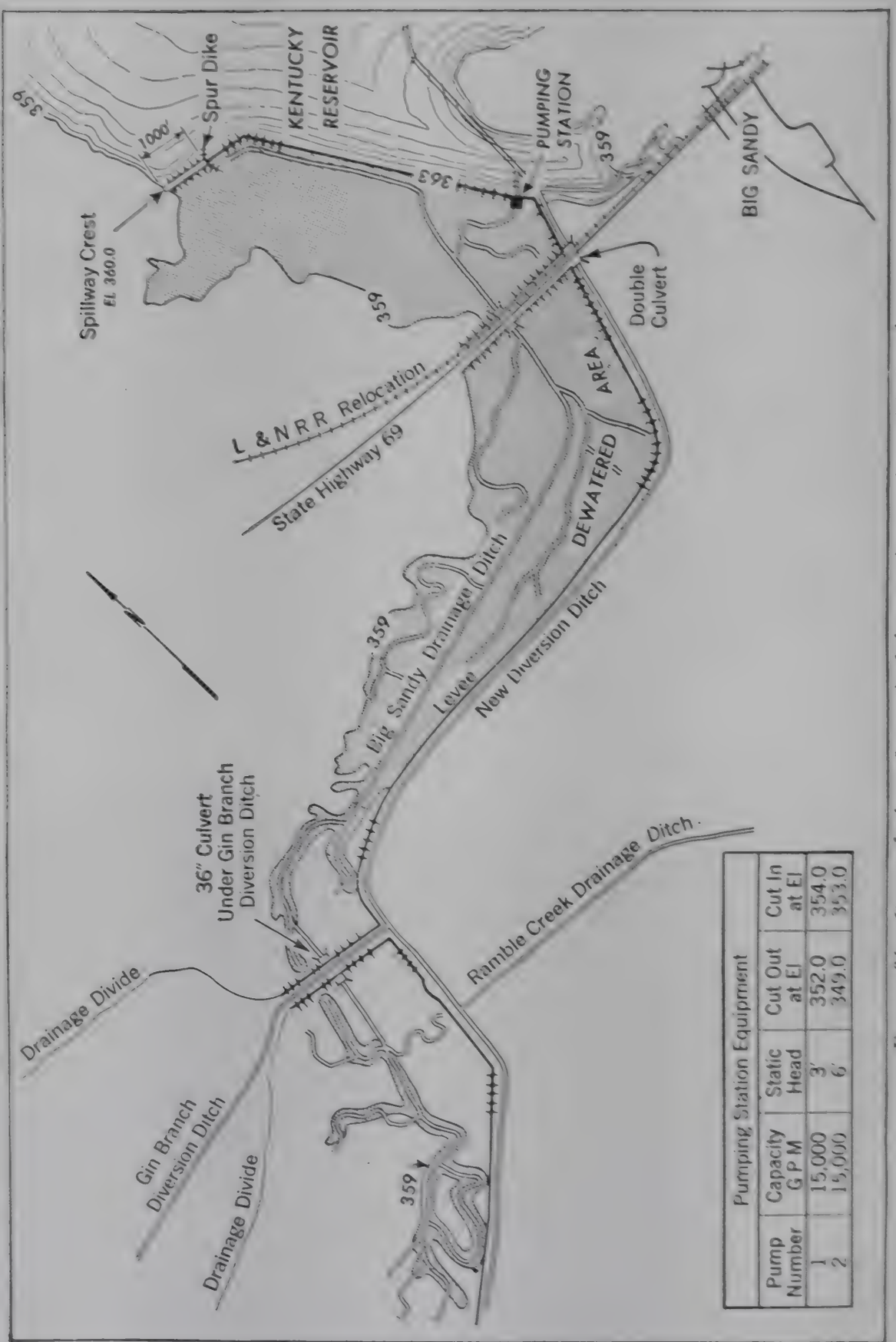

Pumping Station Equipment				
Pump Number	Capacity G P M	Static Head	Cut Out at El	Cut In at El
1	15,000	3'	352.0	354.0
2	15,000	6'	349.0	353.0

FIGURE 31.—General plan of a typical dewatering project—Big Sandy, Kentucky Reservoir, Tennessee River.

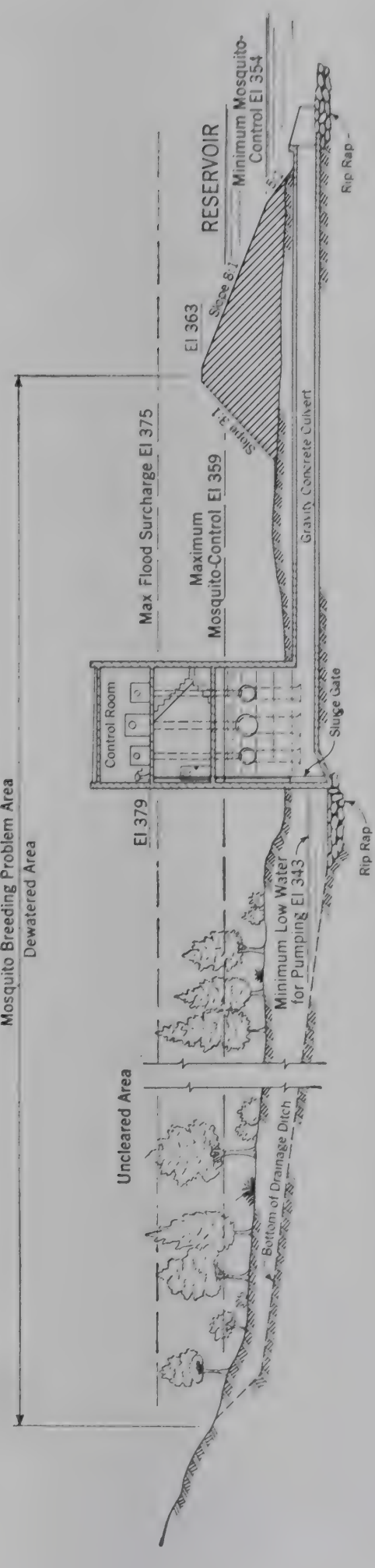

FIGURE 32.—Cross section of a typical dewatering project.

either through or around the dewatered area (see fig. 31). The character of the soil should also be considered in the design, construction, and maintenance of dikes, ditches, and spillways. A thorough geological investigation of the underlying formation is necessary to determine whether seepage may be expected within the dewatered area. The accumulation of relatively minor seepage from a large area might result in excessive pumping costs, and would affect the economics of the project.

Figure 31 is a general plan of a dewatering project (Big Sandy) in the Kentucky Reservoir where a mosquito-breeding problem area in the shallow flats of a tributary stream was eliminated by diking and dewatering. In this particular instance a major portion of the upland drainage was by-passed around the dewatered area through a diversion ditch. (In fig. 31 note the location of dikes, spillways, interior drainage system, diversion channels, and the pump station.)

Figure 33 is an aerial view of the same project showing the diversion canal for Big Sandy River on the left and the dewatered area behind the dike which is in the foreground.

Figure 34 is an aerial view of another dewatering project (West Sandy, Kentucky Reservoir) on a tributary stream where it was necessary to make provision for pumping all of the upland drainage during the mosquito-breeding season.

Timber located within a proposed dewatering area need not be cleared for mosquito control. (See figs. 34 and 35.) The saving on this part of the reservoir preparation may be credited against the cost of the project. If it is desirable to avoid killing the timber by inundation, the pumping plant should be designed so that the area can be dewatered throughout the entire growing season. An occasional flooding of 2 or 3 weeks during this period will not result in serious damage to most bottom-land timber. Flooding during the winter or dormant season usually will not kill the timber.

Where highways and railroad embankments traverse a dewatered area, timber left standing will provide protection from wave action, thus permitting a saving in yardage and embankment protection. A credit on this account did much to justify the permanent improvement program in the Kentucky Reservoir from an economic standpoint. Figure 35 shows an air view of the highway and railroad fills traversing the Camden diking project in Kentucky Reservoir where protection afforded by standing timber permitted the use of steep slopes and sodding as protection for the side slopes which otherwise would have required costly riprap.

If the land inside the dikes is suitable for agriculture and the dewatering schedule prevents "drowning out," revenue from agricul-

FIGURE 33.—Aerial view of Big Sandy dewatering project.

FIGURE 34.—West Sandy dewatering project.

FIGURE 35.—Railroad and highway embankments traversing a dewatering project. (Note dike and pump station in foreground.) Camden, Kentucky Reservoir, Tennessee River.

tural land rental may be credited against the cost of operating and maintaining the project. Agricultural use of land within a dewatered area is shown in figures 30 and 36. Other land uses, depending on the character of the area, may result in values for which a credit can be taken. For example, diking and dewatering projects may serve both malaria control and wildlife conservation interests by dewatering the area in the late spring as a mosquito control measure, and utilizing it for cultivation of wildfowl food plants during the summer. Gradual flooding at the end of the mosquito season, after the food plants have matured, would provide a wildfowl feeding ground. In reservoirs where there is little or no chance of the dikes being overtopped by floods, complete protection of agricultural land might be an objective of the dewatering project. If this is done, the value of the land or saving in land purchase can be credited against the cost of the project.

Table 5 gives pertinent information, costs savings, and other data on a typical dewatering project. Table 6 gives detailed construction costs.

Dike system

With the potential mosquito-breeding areas plotted on a map, the dike should be located so as to embrace as much of the mosquito problem area as possible while minimizing the inclusion of deeper areas and, especially, sizeable areas where no mosquito problem is

anticipated. Frequently it is possible to take advantage of alluvial ridges or natural river levees for the location of the dike, as is well illustrated in figure 29. The soil of a river flood plain is usually suitable for constructing the low dikes that are required. The lake side of the embankment should have a slope of about 1 on 8 depending on the type of soil and exposure to wave action. The land side slope may be steeper, about 1 on 3, when exposure to wave action is limited or the dike is protected by standing timber.

TABLE 5.—*Summary of data for a typical dewatering project*
Big Sandy, Kentucky Reservoir

MALARIA CONTROL DATA		
Shore line	miles	12
Mosquito-breeding problem areas	acres	840
Population within 1-mile zone		875
Gross cost of project:		
1. Levees and drainage	$82,000	
2. Pump station	52,000	
3. Construction overhead	7,000	
		$141,000
Savings on clearing, etc.		85,000
Net cost of malaria control		56,000
Annual costs:		
Mosquito control without dewatering		15,000
Mosquito control by dewatering:		
1. Maintenance and operation	$3,000	
2. Interest on net capital investment @ 3 percent	1,700	
3. Annual amortization cost for a 25-year period @ 3 percent	1,500	
		6,200
Estimated annual savings		8,800
LEVEES AND DRAINAGE SYSTEM		
Total length of constructed levee	linear feet	27,000
Estimated yardage	cubic yards	255,000
Length of ditches, including internal drainage and diversion canals	linear feet	45,340
Estimated excavation	cubic yards	82,000
Right-of-way clearing	acres	40
PUMPING PLANT		
Capacity of plant	30,000 gallons per minute	
Type of motors—75 horsepower	Gasoline	
Maximum draw-down	10 feet	
Size and capacity of pumps	Two 24-inch, 15,000 gallons per minute	
Flap gates	Two 24-inch	
Sluice gates	Two 24-inch	
Gravity outlets	6-by-6-foot culvert	

TABLE 6.—*Detailed construction cost report, Big Sandy Dewatering Project, Kentucky Reservoir—1944*

LEVEES (21,000 LINEAR FEET) AND DRAINAGE DITCHES

	Quantity	Unit price	Amount	Total
Clearing and grubbing	40 acres	$200.00	$ 8,000	
Unclassified excavation	310,000 cubic yards	.20	62,000	
Earth borrow, excavation	27,000 cubic yards	.25	6,750	
Sodding	70,000 square yards	.07	4,900	
				$81,650

REINFORCED CONCRETE PUMP HOUSE

Excavation for structures	3,400 cubic yards	$ 1.00	$ 3,400	
Concrete	449 cubic yards	45.00	20,205	
Reinforcing steel	80,400 pounds	.06	4,824	
30-inch concrete pipe culvert	108 linear feet	3.00	324	
Riprap 12-inch thick	520 cubic yards	3.00	1,560	
Gravel	90 cubic yards	2.50	225	
				$30,538

PUMPING EQUIPMENT

2 gasoline motors and 2 15,000-g.p.m. pumps and auxiliary equipment	$13,895	
Installation of equipment	6,000	
Miscellaneous material and equipment	2,000	
		$21,895
Construction overhead	7,217	
		7,217
Total cost of dewatering project		$141,300

The top of the embankment should, in general, be 3 or 4 feet above the normal summer elevation of the lake or the elevation to which protection is desired. (See figs. 31 and 32.) In determining the height of the levee above the spillway it is especially important to consider the flood crests and backwater curves that are likely to occur on the main reservoir. When tributary streams are diverted around or through a dewatered area (see figs. 31 and 33), it is also important to consider the height of flood crests that may occur in such channels in order to prevent the water overtopping the levees into the dewatered area. In this connection special attention should be given to backwater curves that may develop in these channels as a result of culverts or other constructions or high lake elevations.

Borrow for the dike should be taken from shallow pits well away from and to the lake side of the dike. Land side borrow pits or interior drainage ditches adjacent to the dikes should be avoided to minimize the possibility of seepage and sand boils, especially where the dike is underlain with a previous foundation.

Spillways

Spillways of adequate capacity should be located on natural, flat ground surfaces at sufficient intervals in the dikes to permit filling of the area during anticipated high water. The spillways should have sufficient capacity to permit filling of the area before a head differential is built up that may overtop the dike. Likewise, where there is considerable tributary flow into the diked area, the spillways must have adequate capacity to pass such flows without overtopping the dikes. They should also be designed with ample width to prevent the creation of velocities that would cause scouring. The crest of the spillways should be at the limit of the high water protection desired. Spillways should be graded carefully to the desired elevation and well sodded as a protection against erosion. After construction, the levee system must be checked carefully by leveling to locate any low places or saddles which might be overtopped before the spillways would equalize the water elevations.

Interior drainage system

The interior drainage system should be designed to insure unrestricted flow of water to the pump station In general, the alignment of ditches should follow natural low ground with lateral ditches to

FIGURE 36.—Interior drainage system for a dewatering project—Duck River, Kentucky Reservoir.

provide drainage of depressions removed from the main system. Figure 36 is an air view showing the interior drainage system of the Duck River dewatering project in the Kentucky Reservoir. Where possible, the sump and pump intake should be sufficiently low to permit complete drainage and dewatering of the diked area. In order to minimize excavation and the static lift of the pumps the grades of the drainage ditches should be as flat as possible, but have sufficient slopes to insure drainage in the upper reaches of the dewatered area. Ditch side slopes are designed for the particular soil encountered and may vary from 1 on 1 to 1 on 3. Obviously, the capacity of the main drainage ditch and any structures therein should equal or exceed the capacity of the pump station.

Pumping stations

The primary items to be considered in the design of the pumping plant are capacity, pumping schedule, and operating head. It is necessary in the interest of mosquito control that the pumping plant have sufficient capacity to dewater the area within 15 to 20 days after flooding. The number of pumps and their capacity can then be calculated from the volume of water in the diked area and the expected run-off during the dewatering period. Calculation of the volume of storage to be removed will require contour maps of the area. The run-off may be estimated from rainfall data, drainage area, and factors affecting the run-off characteristics of the area. An example of the preliminary computations necessary in calculating the capacity of a pumping plant is given in table 7.

If the diked area is to be utilized for agriculture, forest lands, or wildfowl feeding grounds, the pumping plant must be designed with these uses in mind, with particular attention being given to possible flooding after the beginning of the growing season. Agricultural use of the land may require dewatering at an earlier date and longer pumping into the late fall, to permit harvesting of crops, than would mosquito control. Use as a wildfowl feeding ground might require pumping water into the diked area at the end of the growing season.

The pumping station should be located at the lower end of the interior drainage system and adjacent to the dike. On the usual project it is advisable to include a gate-controlled gravity flow structure for drainage of the diked area when the elevation of the reservoir will permit gravity flow. This structure may also be used for filling the dewatered area during the winter. The gravity flow structure may be a part of the pumping plant (fig. 37) or a separate structure (fig. 38). Both types were used on the dewatering projects in the Kentucky Reservoir.

TABLE 7—*Preliminary Computation for Design of a Pumping Plant for a Typical Dewatering Project, Kentucky Reservoir*

ENGINEERING DATA

Area of reservoir enclosed by proposed dike.....acres 840
Storage at maximum "mosquito-control" elevation 359.....acre-feet 1,560
Upland drainage area.....acres 3,000
Run-off per month from drainage area.....inches 2
Pumpdown period from maximum "mosquito-control" elevation.....days 14
Total pumping requirements = storage and run-off from drainage area

$$= 1{,}560 + \left(3{,}840 \times \frac{2}{12} \times \frac{14}{30}\right) = 1{,}850 \text{ acre-feet}$$

$$\text{Daily pump capacity} = \frac{\text{total pump requirements}}{\text{time of dewatering}} = \frac{1{,}850}{14} = 132 \text{ acre-feet per day}$$

$$\text{Required pump capacity} = \frac{132 \times 43{,}560 \times 7.5}{1{,}440} = 30{,}000 \text{ g.p.m.}$$

Two pumps each of 15,000 g.p.m. capacity and installed at staggered elevations to permit the most economical operation were used.

COMPUTATION TO DETERMINE RATE OF DRAW-DOWN AT CALCULATED PUMP CAPACITY RATE OF DRAW-DOWN AT ELEVATION 359:

Full capacity 30,000 g.p.m. = 132 acre-feet per day

$$\text{Draw-down (feet per day)} = \frac{\text{Capacity (acre-feet)} - \text{Inflow (acre-feet)}}{\text{Area (acres)}}$$

$$\text{Draw-down (feet per day)} = \frac{132 - \left(3{,}840 \times \frac{2}{12} \times \frac{1}{30}\right)}{840} = 0.13 \text{ feet per day at the beginning of dewatering}$$

COMPUTATION TO DETERMINE AMOUNT OF RAINFALL PER DAY ON DRAINAGE AREA WHICH COULD BE REMOVED BY CALCULATED PUMP CAPACITY

$$\text{Rate of rainfall removable} = \frac{\text{Pump capacity (acre-feet)}}{\text{Total drainage area}} \times 12 = \frac{132}{3{,}840} \times 12 = 0.41 \text{ in. per day}$$

SUMMARY DATA

Pump capacity (g.p.m.)	Acre-feet per day	Inches per day	Storage at top elev. (acre-feet)	Time of pump down in days	Drainage area	
					Total acres	Upland acres
30,000	132	0.41	1,560	[1]14	3840	3000

[1] With an average uniform inflow of 2 inches per month from drainage area.

A typical layout of one of these pumping stations is shown in figure 39. Note the suction well, flap and gravity gates, outlet conduit, trash racks, and fuel storage tank. These should be of a size and design to fit the individual pumping plant requirements. The unusual height of the pumping stations in the Kentucky Reservoir was necessary to protect the power units against a flood surcharge which extends 16 feet above the maximum "mosquito-control" elevation.

FIGURE 37.—Pumping station showing the ports for gravity flow and trash racks for the pump well—West Sandy dewatering project, Kentucky Reservoir.

The usual pump station will require more than one pumping unit for the most economical operation. At the beginning of the dewatering period, all of the units would probably be used, and as the water is lowered the pumps would be cut off at selected elevations. A small unit is usually provided to handle the normal dry weather flow. This unit should be installed so that the water may be drawn down 2 or 3 feet below the general ground elevation of the area to be dewatered, and should cut on and off as required to keep the

FIGURE 38.—Pumping station with separate gravity flow conduits—Camden, Kentucky Reservoir.

water confined to the sump and drainage ditches. Low-head, high-volume, propeller-type pumps are usually most suitable for these projects.

The types of power units are obviously of the greatest importance and should be selected after a careful consideration of many factors, including energy source, maintenance, operation, and first cost. Automatic starting and stopping of the pumps is desirable in minimizing labor costs, and for this purpose electric power is most suitable, but it is not always available at reasonable cost. Gasoline or diesel engines may be used, and can be equipped for automatic starting and stopping, but on a practical operation they must be checked frequently and kept in perfect operating condition. An interior view of the Duck River pumping station, showing gasoline engines with automatic controls, water pump and storage tank, automatic starting control mechanism, and gear boxes for operating the gravity flow control gates, is given in figure 41. Engine rooms, outside electric motors, and control panels should be screened to protect control devices and motor windings from dirt-daubing insects. Maintenance should be anticipated in the design and should include provision for raising the pump for inspection, overhaul, and repair. Specifications

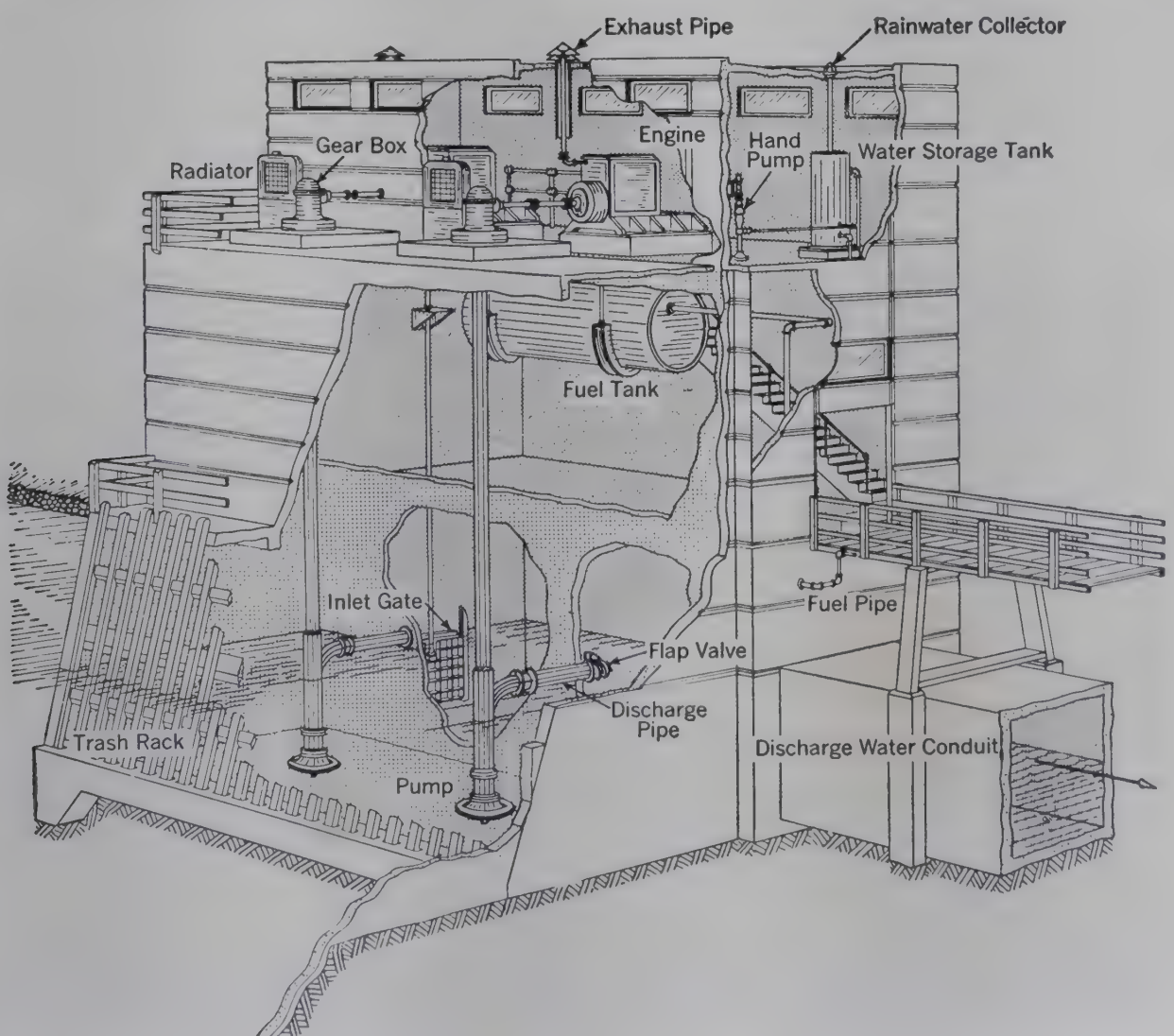

FIGURE 39.—Schematic diagram of a typical pumping station—Kentucky Reservoir.

FIGURE 40.—Pumping station for Big Sandy dewatering project—Kentucky Reservoir.

for pumping equipment should be written so as to insure economical and dependable operation under maximum load conditions.

In the operation of the pumping plant, particular attention should be given to maintaining the equipment in first class mechanical condition. Mechanical service should be available for prompt repairs in case of breakdown. Fire protection, ventilation, and

FIGURE 41.—Interior view of Duck River pump station.

safety features should not be overlooked in the design and operation of the plant. A continuous record of plant operation should be kept in a station log. Automatic gauges to record pumping operations are desirable.

DEEPENING AND FILLING

Filling or raising the ground level to a point above existing water levels has had wide use in land reclamation. It has been used extensively for eliminating shallow mosquito-breeding areas of various types over the world where both natural and artificial means have been employed for raising the ground level to the desired elevation.

Deepening, or filling, is ideal in principle since little or no maintenance is required. However, despite every economy which may be effected, the capital investment for construction will frequently be uneconomical, particularly in large areas where a growth invasion exceeding 2 feet has to be taken into account. In general, deepening and filling has application in small disconnected areas with a high anopheline potential where, for one reason or another, diking and dewatering or other permanent approaches would not be as suitable. This measure was used extensively for the first time on impounded water in the Kentucky Reservoir where it is an important part of the permanent shore-line improvement program.

This method of eliminating marginal mosquito-breeding areas by major topography alteration may be accomplished in three ways; namely, (1) filling the marginal problem zone to a level above the maximum "mosquito-control" elevation, (2) deepening the problem zone to a depth below the lower limit of marginal growth invasion, or (3) a combination of (1) and (2). Normally, the most economical procedure would be number (3) which, theoretically, requires only one-fourth the yardage involved in either (1) or (2), and also effects a much shorter haul. Frequently, however, field conditions will prevent a complete balancing of cut and fill, and this procedure will rarely permit a reduction in quantities exceeding 50 percent. A plan and profile of a typical deepening and filling project are shown in figures 42 and 43. Figure 43 shows the slope of the new shore line, depth of water in the cut area, and allowance for settlement and construction tolerance in the fill area.

In the Kentucky Reservoir a 3-foot growth invasion was assumed in designing cut and fill projects. They were constructed prior to impoundage, using conventional earth-moving equipment. Figure 44 is a view of a cut and fill project showing the new shore line and stump piles in the cut section ready for burning. Views of a completed project after impoundage are shown in figures 45 and 46.

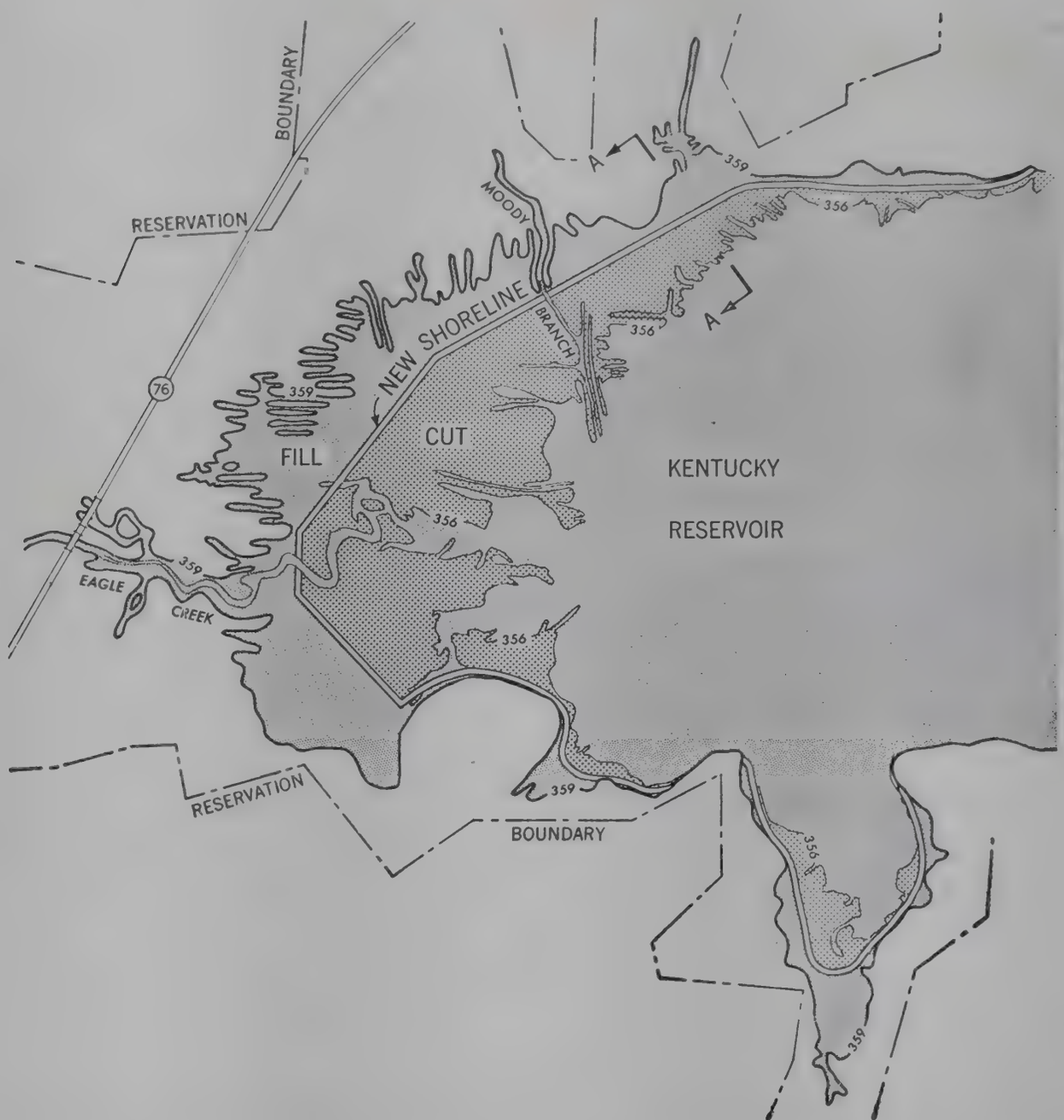

FIGURE 42.—Plan map of a cut and fill project—Eagle Creek, Kentucky Reservoir.

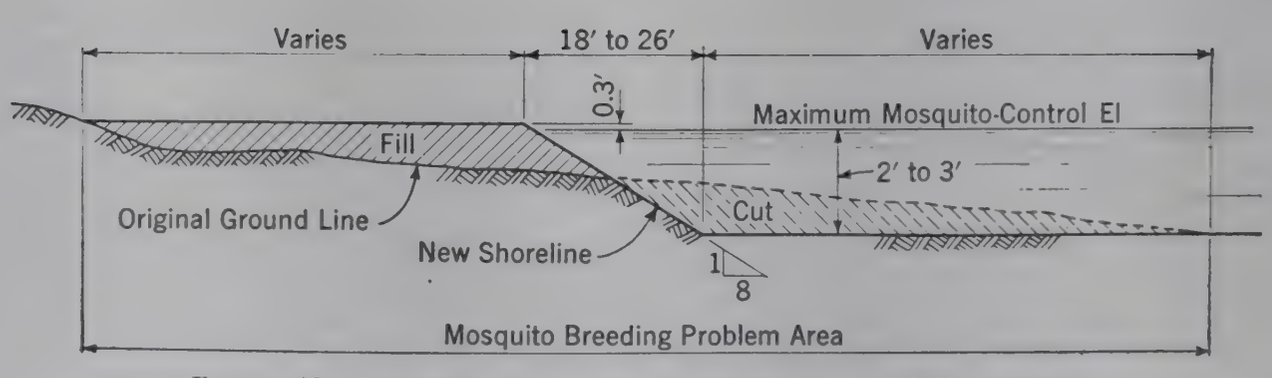

FIGURE 43.—Diagrammatic cross section of a cut and fill project.

FIGURE 44.—Completed cut and fill project—Blood River, Kentucky Reservoir.

As in the case of diking and dewatering, tentative selection of the areas proposed for cut and fill should be made on the basis of the need and suitability of the individual areas for this approach. The preliminary study of the reservoir and the cost of an antilarval program may be utilized in examining the feasibility of applying this method of shore line improvement.

Good topographic maps are required for planning and designing a cut and fill project. One-foot contours in the proposed improvement area are necessary for accurately estimating the earthwork involved. Detailed plans should be developed on maps to a scale of about 1 inch equals 200 feet, and should indicate the cut and fill

FIGURE 45.—Aerial view of a deepening and filling project after impoundage—Eagle Creek, Kentucky Reservoir.

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FIGURE 46.—Close-up of Eagle Creek project.

areas, upland borrow areas, the new shore line, the amount of grubbing in borrow areas, etc. It will be advisable during construction to permit field adjustments for any unusual or unforeseen conditions which might develop. In estimating the yardage required for fill sections, an allowance should be made for compaction and settling. On the Kentucky Reservoir cut and fill projects, shrinkage and compaction resulting from the heavy earth-moving equipment necessitated a 30 to 40 percent increase in the theoretical fill requirements. For all practical purposes the top of the fill section may be flat and extra refinements are not necessary in the grading. Drainage can be provided by small furrows or hand ditches after settlement of the fill has taken place. Some minor depressions may develop as a result of uneven settlement which can be filled with earth from stock piles left for this purpose, or borrow can be taken from the face of the fill section. It is considered advisable to set the top elevation of the fill about 1 foot above the maximum "mosquito-control" elevation. The bottom of the cut section should be at or below the lower limit of marginal growth invasion.

A stable slope, about 1 on 8 for most soils, should be used for the new shore line. Usually protection of the slope is unnecessary. In laying out the new shore line and in balancing the cut and fill, it is desirable to use straight lines and sweeping curves and to avoid protected pockets and embayments. Natural drains running through the fill section should be of ample section with flat side slopes so that erosion and meandering will be minimized. It is especially important that the grade of the fill section be extended until it intersects the grade of the natural ground to avoid the formation of pockets which might hold water and thus be a source of mosquito breeding.

The following table shows the summary of a deepening and filling project.

TABLE 8.—*Eagle Creek deepening and filling project summary Kentucky Reservoir, Tennessee River*

Length of shore line before filling	miles	11.5	
Length of shore line after filling	miles	2.9	
Mosquito problem area filled	acres	78.8	
Mosquito problem area deepened	acres	76.3	
Total problem area eliminated	acres	155.1	
Population within 1-mile zone		365	
Population density per square mile		57	
Earth moved in deepening and filling	cubic yards	128,000	
Cost of project including clearing, excavation, etc.			$50,500
Annual costs:			
Mosquito control without deepening and filling:			
1. Larviciding		$1,900	
2. Growth removal		1,600	
3. Drainage maintenance		500	
			4,000
Mosquito control with deepening and filling:			
1. Larvicides		$ 300	
2. Growth removal		100	
3. Drainage maintenance		200	
4. Interest on capital investment @ 3 percent		1,500	
5. Annual amortization cost for 25-year period @ 3 percent		1,400	
			3,500
Estimated annual savings			500

FIGURE 47.—Earth-moving equipment used in deepening and filling operations.

Prior to construction, the soil should be examined to determine where boggy conditions may develop and prevent the use of conventional earth-moving equipment, such as tractor-scrapers, bulldozers, or graders. A dragline was used in one boggy situation in the Kentucky Reservoir where wheel equipment could not be used in the cut area. The installation of drainage in marshy areas may be used to improve ground conditions ahead of construction. On impounded reservoirs cable-operated drag scrapers offer a possibility for cut and fill operations under boggy ground conditions. Hydraulic dredging may sometimes be used for filling, particularly in situations where land equipment cannot be employed due to unfavorable ground conditions. Any mounding or uneven distribution of material placed by the dredge can be leveled with a bulldozer or road grader. It is not considered feasible or economical to use dredges for effecting the combined cut and fill procedure previously described.

LOW DAMS FOR SUPPLEMENTAL WATER LEVEL MANAGEMENT

The construction of low dams with water control structures to provide better water level management on tributary arms of a main reservoir is another engineering measure which has had little practical application. However, this measure is briefly reviewed here as a possible alternate means of minimizing the mosquito-breeding potential in areas where other more effective permanent measures cannot be applied. Such low dams do not eliminate the mosquito-breeding problem, as in the case of dewatering or filling, but in certain situations they may reduce the anopheline potential through improved water level management, independent of the main reservoir, and permit a successful and economical antilarval program. In some situations, the use of tributary dams may also make it possible to increase the water depth over shallow mosquito-breeding areas, and establish a top pool level on a steeper shore line, thus greatly decreasing the mosquito production potential of the area.

This measure would be most applicable to tributaries of a reservoir with a water level schedule unfavorable for mosquito control and where other permanent shore-line improvements would be impractical. In considering this measure, it is essential to obtain a water level schedule greatly improved over that which might be available on the main reservoir. The economic feasibility of such a project would depend upon the location of a suitable dam site, the cost of construction, the amount of additional clearing above the basic clearing line, and the cost of operating the control structure.

In considering the design of a lateral impoundage, the maximum "mosquito-control" elevation (for the lateral impoundages) should

be set 2 or 3 feet above that of the main reservoir with provision for a surcharge of 2 to 4 feet. The surcharge may be used in advance of the mosquito season to strand drift and vegetation, with periodic water level fluctuation or seasonal recession combined with periodic fluctuation being employed for mosquito control during the season. Stream flow records and evaporation data should be studied to ascertain whether the inflow will be adequate to provide the water level management desired. Under certain conditions, the dam and water level control structures might be used to advantage in holding out, either temporarily or completely, the occasional high water level resulting from summer flood flows on the main reservoir. A discussion of water level management schedules for mosquito control may be found in chapter V.

Local topography and foundation conditions will govern the location and type of the dam. An adequate spillway should be provided to pass flood flows. Control of the water level may be obtained by the use of flashboards or gates, or a combination of these. Regular attendance will be required during the season of periodic fluctuation for operation of water control structures.

LAND-USE RESTRICTION

The effectiveness of limiting the use of land near swamps and

FIGURE 48.—Aerial view of a land-use restriction area showing prolific mosquito-breeding area and sparse population—Daniel's Landing Area, Kentucky Reservoir.

other mosquito-breeding areas to daytime activities was recognized as a means for preventing malaria even before the nature of the disease or its vector was discovered. This method of malaria control is one of unquestioned effectiveness because it provides for moving the population beyond the effective flight range of mosquitoes produced in the lake.

This method of malaria control has been used in several instances in the past. It was used in a sparsely settled section of the Kentucky Reservoir and was considered for certain sections of Sardis Reservoir in Mississippi. On the Kentucky Reservoir, easements were taken on the land within 1 mile of the reservoir which permitted all normal uses of the land except that the people were required to live beyond the 1-mile limit and to keep out of the area at night during the mosquito season. A similar approach was used earlier on an impounded water project in west Florida, where all land within 1 mile of the reservoir was purchased to avoid an expensive antilarval program which promised little success under the conditions. Obviously, antilarval measures are not necessary as a malaria control measure where no people live within mosquito flight range.

This method of malaria control is most adaptable to sparsely populated zones bordering prolific mosquito-breeding areas of the reservoir, which would be difficult to control with conventional antilarval measures, or where shore-line improvements previously discussed would not be feasible or economically practical. Generally, the land would not be particularly suited for agriculture and not likely to be otherwise in demand for habitation. The particular section where land-use restriction was applied in the Kentucky Reservoir was rugged cut-over timberland with very limited agricultural possibilities (fig. 48). The combination of circumstances which indicate the employment of land-use restriction is relatively rare.

In developing a land-use restriction project, it is especially important that all the facts be established and properly evaluated. One of the first items to be considered is an appraisal of the land, including a study of various means for providing land-use restriction. This investigation may indicate the purchase of the land in fee simple or the purchase of easements to provide the desired restrictions. In either event, a normal use of the land for timbering, farming, grazing, etc., can be continued, with only the restrictions necessary to prohibit the occupation or construction of dwellings within the mosquito flight range zone and night occupancy of the area during the mosquito season. The occasional camper, temporary trespasser, or person traveling through the area at night is not of consequence in malaria transmission. At this stage of the study it would be well

to ascertain whether or not the people will support the land-use restriction program. As a matter of public relations, it is doubtful if a land-use restriction program should be undertaken without the support of a considerable majority of the people affected.

The purchase of the land or the acquisition of easements may amount to a substantial figure, but credits may be taken for savings in reservoir preparation, investment for facilities and equipment for application of antilarval measures and, of course, the saving in mosquito control maintenance after impoundage. It might be permissible under certain circumstances to eliminate all clearing, drainage, or other preimpoundage reservoir preparation for mosquito control, in which case a very substantial saving would result. This, in itself, might be enough to offset entirely the purchase of the 1-mile zone or the acquisition of easements. All of these items were saved on the land-use restriction project in the Kentucky Reservoir, except that some clearing was carried out for purposes other than malaria control. Another saving might be made in avoiding highway or road relocation otherwise necessary where access roads are flooded in the 1-mile zone.

It might be desirable to carry out a limited clearing operation in order to remove timber that would be killed by flooding, and thus create drift which might subsequently reach other portions of the reservoir where land-use restriction was not in effect. Other program interests, principally navigation and protection of dam structures from floating logs and debris, might also require limited clearing in land-use restriction areas.

PERMANENT MARGINAL GRAZING

Experience in many reservoirs throughout the country has indicated that pasturing of marginal lake areas has been effective in restricting the growth of marginal plants and inhibiting the production of anopheline mosquitoes. In some areas especially favorable for pasturage, marginal grazing in combination with water level management may provide a continuous and inexpensive means of growth removal, and thus limit or eliminate the need for applying larvicides. Marginal grazing has also been used extensively as a part of marginal land-use with incidental benefits to mosquito control. While this approach has value, it cannot be depended upon normally to result in a degree of growth control comparable to that resulting from a permanent grazing program planned specifically for malaria control. A permanent marginal grazing project, which is properly planned, developed, and managed, will provide continuous and progressive removal of growth; whereas mechanical removal

is generally scheduled as a post-season operation to inhibit mosquito breeding the next year. Grazing will increase the effectiveness and decrease the cost of supplementary antilarval measures while providing profitable utilization of marginal land.

In general, grazing as a permanent malaria control measure can be profitably and successfully employed only where a combination of certain circumstances exists; namely, an anopheline potential sufficiently high to require a considerable outlay for conventional growth control measures and application of larvicides, a marginal area having some slope in well-drained upland terrain of medium to poor soil fertility, and a reasonably adequate water level management for mosquito control. Experience has indicated that grazing alone is not very effective as a growth control measure in flat and fertile flood plains characterized by lush growth and conditions exceptionally favorable for anopheline mosquito breeding. Under these conditions, the type of marginal plants and their rapid growth frequently prevent grazing from being sufficiently effective to retard the development of a favorable environment for mosquito production. Furthermore, a predominance of plants not ordinarily eaten by stock is frequently found in such flood-plain areas.

A further requisite of a properly planned grazing project is adequate upland pasture separated from the lake pasture by a contour fence. Where an upland and a marginal pasture are interconnected by proper gaps or gates, grazing may be alternated between the two with periodic forced grazing along the margins of the lake as required. Figure 49 shows a map of a typical dual-pasture layout. Removable electric fences may sometimes be used to confine livestock in the marginal areas contiguous to reservoirs with wide drawdowns. Such fences can readily be installed or removed as the pool level fluctuates.

The first consideration in the establishment of permanent grazing as a malaria control measure is the availability and demand for pasture in the territory of the project. In many areas a lease can be made sufficiently attractive to adjacent property owners to insure controlled grazing as required in the interest of malaria control. Management of grazing areas should be a cooperative arrangement between malaria control and land management interests. Agricultural agents can be of considerable assistance in working out agreements and obtaining leases. Where possible, it is desirable to execute long-term leases under controlled grazing practices with provision for the application of any necessary supplementary growth removal by mechanical or herbicidal means.

There are some plants, such as stinkweed, rushes, and smartweed, on which cattle do not readily feed. Where these plants grow in the marginal pasture in sufficient density to be significant in mosquito production, periodic removal by either mechanical means or by herbicides is necessary. The new formagen weed killers, such as 2,4-d (see "Herbicides," ch. VI), are quite promising for this purpose and are not injurious to cattle. Arsenical herbicides should not be used in pastures; also paris green applied as a larvicide must be carefully administered and controlled in marginal areas devoted to grazing.

In the type of areas previously discussed, permanent grazing combined with favorable water level management will usually provide adequate mosquito control without the use of larvicides. However, periodic removal of annual and terrestrial plants which are not effectively reduced by grazing may be required. In the event of the development of a temporarily unfavorable circumstance when grazing does not prove effective in the control of malaria, supplementary measures, such as larviciding, house-spraying, mosquito proofing, or other means applicable in an emergency may be required.

The development of permanent grazing facilities may be justified in the same manner as a dewatering or filling project. The feasibility of the capital investment for fences, etc., may be deter-

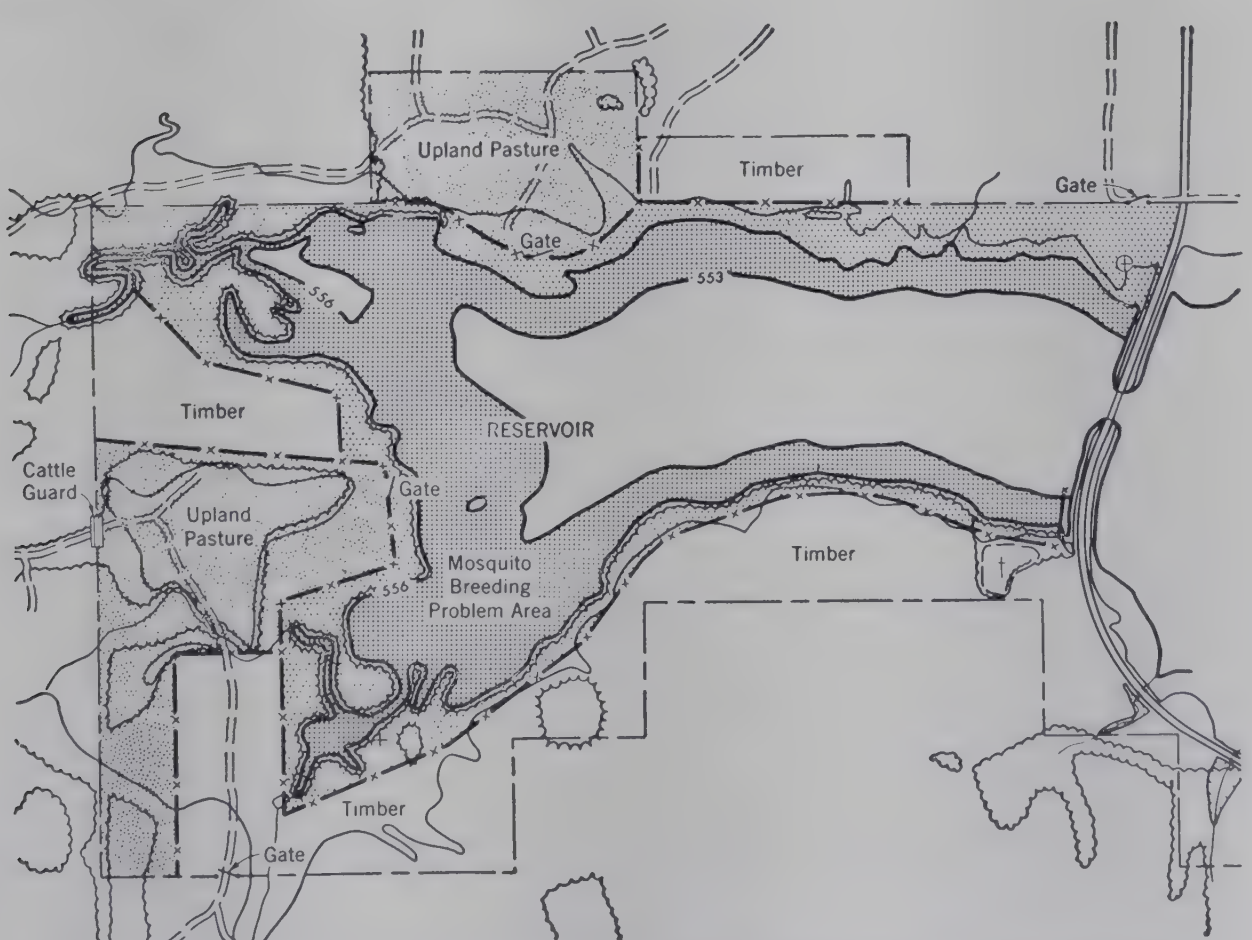

FIGURE 49.—Map of typical dual-pasture system for permanent marginal grazing.

mined by comparing the costs of this measure with other antilarval measures. Where ownership of sufficient upland marginal area is held, permanent grazing can, as a rule, be developed at less cost than other permanent approaches. Study and development of permanent grazing projects should be considered along with studies of other types of malaria control. Approval or concurrence in grazing as a permanent approach, as well as other measures, should be sought from the State health department. Grazing is further discussed in the chapter on shore-line maintenance.

The following table gives pertinent information regarding the features involved and costs of a permanent grazing project.

TABLE 9.—*Features and costs of a typical grazing project*

Length of shore line.....miles	40	
Mosquito problem area.....acres	500	
Upland pasture.....acres	1,200	
Gross cost of project:		
1. Fencing—26½ miles @ $350	$9,300	
2. Gates—30 @ $30	900	
3. Cattle guards—7 @ $250	1,750	
4. Minor topography alterations[1]	5,000	
		$16,950
Annual costs:		
Mosquito control without grazing		
1. Larviciding (airplane dusting)	$3,650	
2. Growth removal	4,000	
3. Miscellaneous	150	
		7,800
Mosquito control with grazing		
1. Maintenance of fencing	$1,000	
2. Periodic removal of ojectionable plants not grazed	1,000	
3. Interest on capital investment @ 3 percent	500	
4. Annual amortization cost for a 10-year period @ 3 percent	1,500	
		4,000
Estimated annual savings		3,800

[1] Topography alterations necessary to reduce the anopheline breeding potential in the area to be grazed.

V. WATER LEVEL MANAGEMENT

HISTORY

The development of water level management practices for malaria control on impounded water projects had its inception about 1914, at which time the United States Public Health Service first undertook studies of the occurrence of malaria around impoundages and the factors related to production of the malaria vector. These studies, as previously discussed in chapter I, demonstrated the effectiveness of water level fluctuation for controlling or inhibiting the production of malaria mosquitoes.

As a result of these studies by the Public Health Service and various State health departments, many of the States in the Southeast passed regulations governing the impounding of water. Provision for water level management is a specific requirement of several of these State regulations. For example, the Tennessee regulations state:

> It shall be the duty of the person responsible for an impoundage to carry out controlled water level management at any season of the year in the manner and amount as may be specified in writing by the Commissioner.

In general, the various State regulations permit the owners of the impoundages wide latitude of choice in the use of water level management in combination with other measures. This is necessary because of the varied uses of impounded water projects, and the many factors having a bearing on water levels preclude fitting any given schedule to all projects.

During the period 1920-30 water level management, particularly periodic water level fluctuation during the mosquito season, was used to advantage in mosquito control on several hydroelectric projects. However, the single purpose reservoir of this period was usually small and located in relatively steep topography, and thus did not offer the problem created by many of the multipurpose projects constructed since 1930 in flatter topography.

The Tennessee River development is typical of the multipurpose projects which posed new problems of malaria control on impounded water, and required water level management practices for malaria control that offered the least amount of interference with the primary purposes for flood control, navigation, and the generation of power. From the beginning, water level management was considered to be the single most important mosquito control meas-

ure which could be employed. The problem was to fit it into the above primary purposes and to improve water-level management techniques.

The primary purposes of some impounded water projects require water level management schedules very adverse to mosquito control. Typical of these are the single-purpose flood-control reservoirs with unpredictable water-level schedules. However, the probable frequency of the pool reaching various elevations during the mosquito-breeding season is generally known. Also, adverse water level schedules are sometimes necessary on other projects constructed for navigation. Projects of these types will require the development of effective means of malaria control without the benefit of favorable water level management.

BASIC PRINCIPLES OF WATER-LEVEL MANAGEMENT

Successful use of water level management for mosquito control is dependent upon the knowledge and recognition of a number of biological facts, one of the most important of which is that the larvae of anopheline mosquitoes require an environment of plants and flotage. Anopheline larvae are not found on clean water surfaces of an impoundage. The important factor in the propagation of anopheline mosquitoes is the intersection of the water surface by vegetation and flotage. The linear amount of this intersection line determines the anopheline breeding potentials of different types of plants and breeding situations. (See "Effect of Plants on Mosquito Production," chap. XIII.) Other factors being equal, it has been

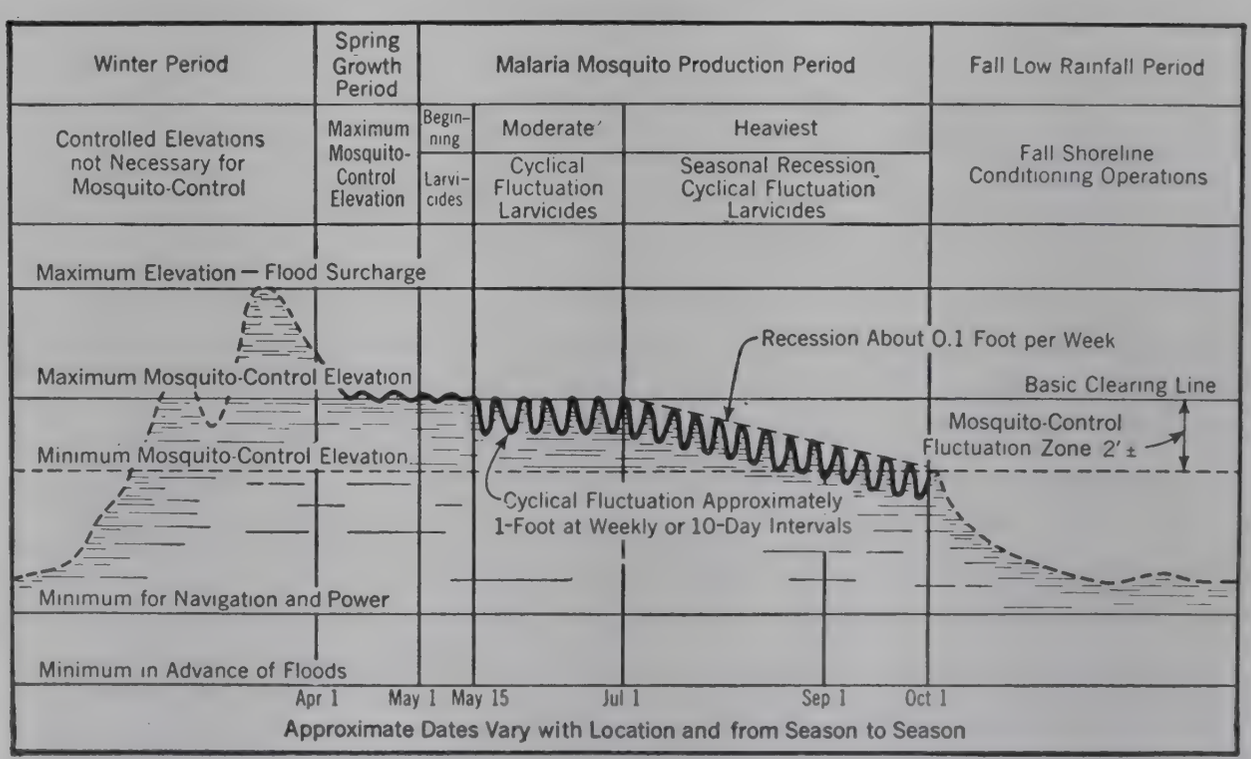

FIGURE 50.—Desirable phases of water level management for mosquito control on main-river reservoirs.

observed that where there is little vegetation at the water's surface, thus resulting in a low intersection value, few larvae are found; and that as the intersection line increases, it is accompanied by an increase in the number of anopheline larvae.

One of the most important objectives in water level management for mosquito control is the manipulation of the water level so as to eliminate or minimize the intersection line in mosquito-breeding areas along the margins of the reservoir at the proper time and intervals. The effect of water level manipulations on anopheline larvae is both direct and indirect. The direct effect is on the larvae themselves as a result of drawing the water out of the marginal vegetation thus exposing them to an open and clean water surface situation wherein very few can survive. The indirect effect is on the marginal plants and drift and flotage which provide food and protection for the larvae.

PHASES OF WATER LEVEL MANAGEMENT AND THEIR APPLICATION

Water level management for the control of anopheline mosquitoes may consist of various phases of water level control including:

Initial filling
Surcharge
Constant level
Fluctuation
Seasonal recession

They may be used singly or in combination. The combined

FIGURE 51.—Stranding of drift and flotage by use of a surcharge.

use of these various phases, as applied to a run-of-river reservoir on the Tennessee River, is shown in figure 50. Each of the phases is discussed in the succeeding paragraphs.

Initial filling

It is so important that the initial filling of a reservoir occur during the winter that this may be considered as the first phase of water level management for mosquito control. The initial impoundage should not occur during the summer, for otherwise an uncontrollable mosquito-breeding situation may develop. The benefits of cleaning the "mosquito-control" fluctuation zone at the end of the last growing season, as indicated in chapter III, will largely be lost if impoundage occurs after the next growing season has begun. A particular point in this connection is that a much shorter period of flooding is usually required to kill a stump which has no sprouts than is required for one which has sprouts projecting above the water surface. This also holds for certain perennial marginal plants. Summertime impoundage should be avoided particularly on run-of-river reservoirs of flat topography where the most favorable water level management is required for adequate mosquito control.

Surcharge

Many reservoirs, and especially run-of-river projects, are designed for a surcharge to provide a space for temporary storage of water above the basic clearing line for the control of floods. Where this surcharge is used in advance of the mosquito season, it is of great value in anopheline mosquito control through stranding of drift and flotage (fig. 51). In order to make its use most effective, it is necessary to maintain the shore line free of coppice and stiff-stemmed

FIGURE 52.—Drift and flotage prevented from stranding by emergent growth.

herbs which would otherwise prevent stranding of the flotage by extending above the lake level (fig. 52).

If a surcharge is used after the growing season has begun, but in advance of the mosquito season, it also limits the growth of marginal plants. The use of the surcharge zone would occur normally during the flood season in the late winter or early spring. Occasionally summer floods require the use of the surcharge zone. Such summer flooding is undesirable in the control of anopheline mosquitoes due to the filling of small depressions and the possibility that flood waters may remain in the uncleared margin for a period exceeding a week or 10 days; thereby resulting in the production of a brood of mosquitoes. However, when the water must be raised temporarily above the clearing line in the summer, some incidental benefits may result from the stranding of any drift and flotage. In addition, invading marginal terrestrial vegetation would be killed, checked, or possibly defoliated by a few days' submergence. As flood control operations are generally transitory in character with a rapidly rising and falling level, they are not likely to increase seriously mosquito production, provided the period of departure above the clearing line or "rule curve" does not exceed a week or 10 days. In most of these situations it will be desirable to place greater emphasis on limiting the time the water is maintained above the clearing line than on limiting the maximum elevation reached.

Impoundment designers and operators should clearly understand that water should not be stored above the maximum "mosquito-control" elevation for long periods during the mosquito season. If this is anticipated or should become necessary after construction, then marginal clearing, drainage, and other indicated reservoir preparations should be applied to the upper limit of the anticipated summer elevation. In other words, after the designers have fixed the operating levels, these levels should then be strictly observed because the water level management program will be based on them.

It has been found that a surcharge with a scope of about 4 feet is necessary for the most effective stranding of drift and flotage in average topography. However, a 1- or 2-foot surcharge can be utilized to advantage if no more can be provided, and even a 6-inch surcharge is definitely beneficial. A surcharge used for only a day or so has been observed to be effective for stranding drift and flotage.

Where a surcharge is not available or cannot be provided, the antilarval program must anticipate accumulations of drift and flotage which will increase the anopheline production potential. If drift is of sufficient importance, it may be removed by mechanical methods in the absence of effective stranding through use of a surcharge.

However, it is not the usual practice to undertake the removal of flotage in this manner since it tends to sink or be cast on the bank by wave action. If possible, all major run-of-river projects on which an anopheline mosquito problem is anticipated should be provided with a surcharge.

Constant level pool

In water level management for mosquito control, it is desirable to bring the water to or above the maximum "mosquito-control" elevation by the beginning of the growing season, where it should be maintained with a minimum of fluctuation until the beginning of significant mosquito production. This phase is used to delay the development of marginal vegetation. The success of subsequent water level manipulation for anopheline mosquito control depends to a large degree upon the use of the constant level phase. If the shore line within the fluctuation zone is dewatered even for a few days during the spring growth period, many plants will sprout and produce a growth which will survive even though reflooded. This may interfere later with the effectiveness of water level manipulation. Moreover, the downward invasion of growth will be increased, thus adding to the expense of removal operations at the end of the season. When a constant level pool can be maintained during the fruiting period of certain objectionable plants, it will limit the depth in the reservoir to which floating seed will be stranded and take root. Where the constant level pool phase is applicable, it may be sufficiently valuable as a growth control measure to extend it into the beginning of the anopheline breeding season, even though the use of some larvicides is required. This is done in order to have a cleaner shore line later in the season when more effective mosquito control is necessary.

Cyclical fluctuation

The fourth feature of water level management is periodic water level fluctuation. This phase of water level control should be initiated when moderate production of mosquitoes is beginning. Its effectiveness in larvae control is determined mainly by the duration and extent of the draw-down below the marginal vegetation. It has been found that a periodic fluctuation of at least 1 foot is usually required for reasonable effectiveness in the average reservoir. The cycle should be completed once every 7 to 10 days. In some instances normal water uses may result in the periodic fluctuation desired, or it may be scheduled specifically for mosquito control. In any event,

FIGURE 53.—Water in marginal vegetation at top of fluctuation cycle.

FIGURE 54.—Water out of marginal vegetation at low point of fluctuation cycle.

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there must be sufficient inflow to refill the reservoir to the maximum "mosquito-control" elevation at the end of each draw-down period, or to the rule curve where progressive recession is being employed in conjunction with periodic fluctuation.

The effectiveness of cyclical fluctuation is dependent upon the water's being drawn out of marginal vegetation at the low point of the cycle, thus exposing the larvae to stranding, natural predators, and the adverse effects of increased exposure to wave action. It has been observed that there is a decrease in mosquito oviposition with periodic fluctuation, and that it also decreases the production of epiphytic algae and plankton which serve as food for larvae. When the water level is brought back to the top of the cycle and held there for 2 or 3 days, it tends to retard the invasion of marginal plants. Figures 53 and 54 are views of water at the high and low elevations on a schedule of cyclical fluctuation.

It should be pointed out that cyclical fluctuation is not equally effective for all types of marginal and aquatic plants. Flexuous plants rooted in the margins and lying on the surface, as well as the floating leaf and floating mat type, provide a habitat in which mosquito production is not very effectively controlled unless the plants are entirely dewatered.

In some reservoirs cyclical fluctuation alone may be adequate for mosquito control, provided it is of sufficient scope. This will vary with the character of the shore line, but at least 1½ to 2 feet or more are usually necessary for the average reservoir. Where seasonal recession can be combined with periodic fluctuation, a lesser scope of fluctuation and recession is required than for either employed alone. If there is a choice and results would be comparable, periodic fluctuation alone would be preferred to a combination of fluctuation and recession since there would be less marginal growth invasion.

Most frequently, in planning or anticipating periodic fluctuation, it is necessary to assume some irregularity in the scope and timing of the cycle. This will occur with variations in stream flow, power load, and other water use demands. In reservoirs where it is necessary or advisable to combine periodic fluctuation with seasonal recession, the latter phase should not be initiated until it is actually necessary for current mosquito control.

In a chain of reservoirs, apparent conflicts between mosquito control fluctuation and water uses for power may frequently be resolved with little or no loss of power by alternately raising and lowering the hydraulic head on successive impoundages.

Seasonal recession

Seasonal recession is a common type of water level control that

may be employed advantageously alone or in combination with cyclical fluctuation for mosquito control. On many projects, seasonal water level recession is a normal operation in which stored water is gradually released during the dry season for one or more purposes, as for power development, flood control, navigation, irrigation, and domestic or industrial water supply. Where the reservoir has been properly prepared and subsequently maintained, recession may facilitate mosquito control, provided the time of the beginning and the rate of recession can be adjusted to meet the needs of mosquito control. The amount of recession needed for mosquito control will vary with individual reservoirs. Where used with periodic fluctuation, a rate of recession of about 0.1- to 0.2-foot per week, beginning about July 1, has generally given very satisfactory results on the Tennessee River reservoirs. Where used without periodic fluctuation, a recession of from 0.2 to 0.3 foot per week should be adequate, beginning somewhat earlier than July 1. In practice, these figures should be flexible and subject to seasonal variations in accordance with the current needs on individual reservoirs.

Water level recession should not begin earlier or occur at a faster rate than actually required for mosquito control. This will require a very careful consideration of the relative need for and effects of this phase of water level management in relation to other phases and supplemental antilarval measures. Frequently, decisions must be made on the basis of relative costs as well as the results to be obtained.

Where water level recession alone is utilized or scheduled for mosquito control, an earlier starting date and faster rate of fall are required than where this phase can be combined with periodic fluctuation. Needs will vary widely according to topography, type of marginal growth, and the seasonal start of anopheline production. The normal storage reservoir is usually filled during the rainy season of late winter and spring, with draw-down or the use of stored water being initiated during the early summer or start of the dry season. An example of the effectiveness of controlled recession below the basic clearing line in a flood control reservoir located in a rather mountainous region is well illustrated in figure 55. In this instance, satisfactory mosquito control was achieved without the use of larvicides. Such operation serves mosquito control needs quite well since with recession there will be a progressively improving shore line condition. Figure 56 shows a view of a clean shore line following water level recession in a storage reservoir properly cleared.

General considerations

The successful utilization of water level management for mos-

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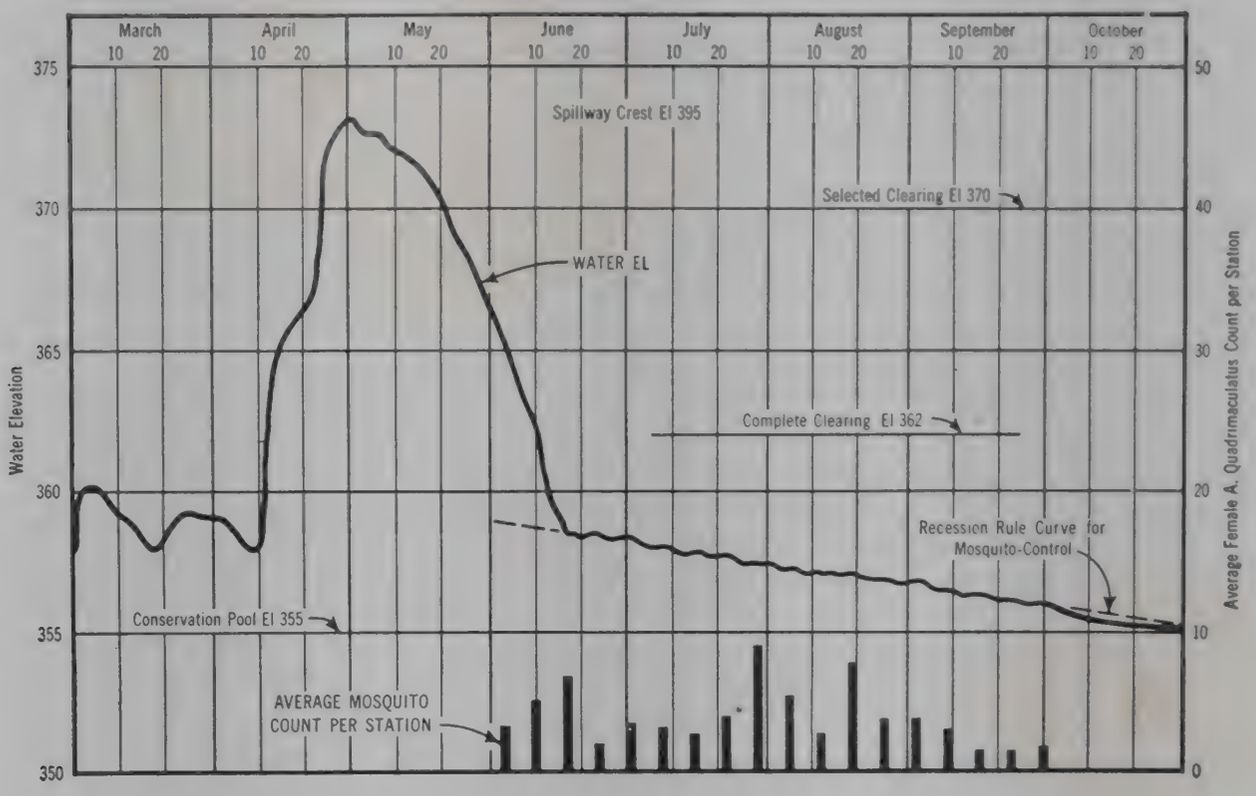

FIGURE 55.—Desirable water level management for mosquito control on a flood control reservoir. Wappapello Reservoir, Missouri (1944).

quito control is not solely dependent upon the proper manipulation of water elevations but depends also upon the carrying out of certain accessory measures. The most important of these accessory measures are (1) proper reservoir preparation including reservoir clearance, marginal drainage, and final reconditioning of the zone of fluctuation, and (2) shore-line maintenance including annual shore-line conditioning, aquatic growth control, marginal grazing, and drain-

FIGURE 56.—Clean shore line following recession in a storage reservoir properly prepared. Chatuge Reservoir, Hiwassee River.

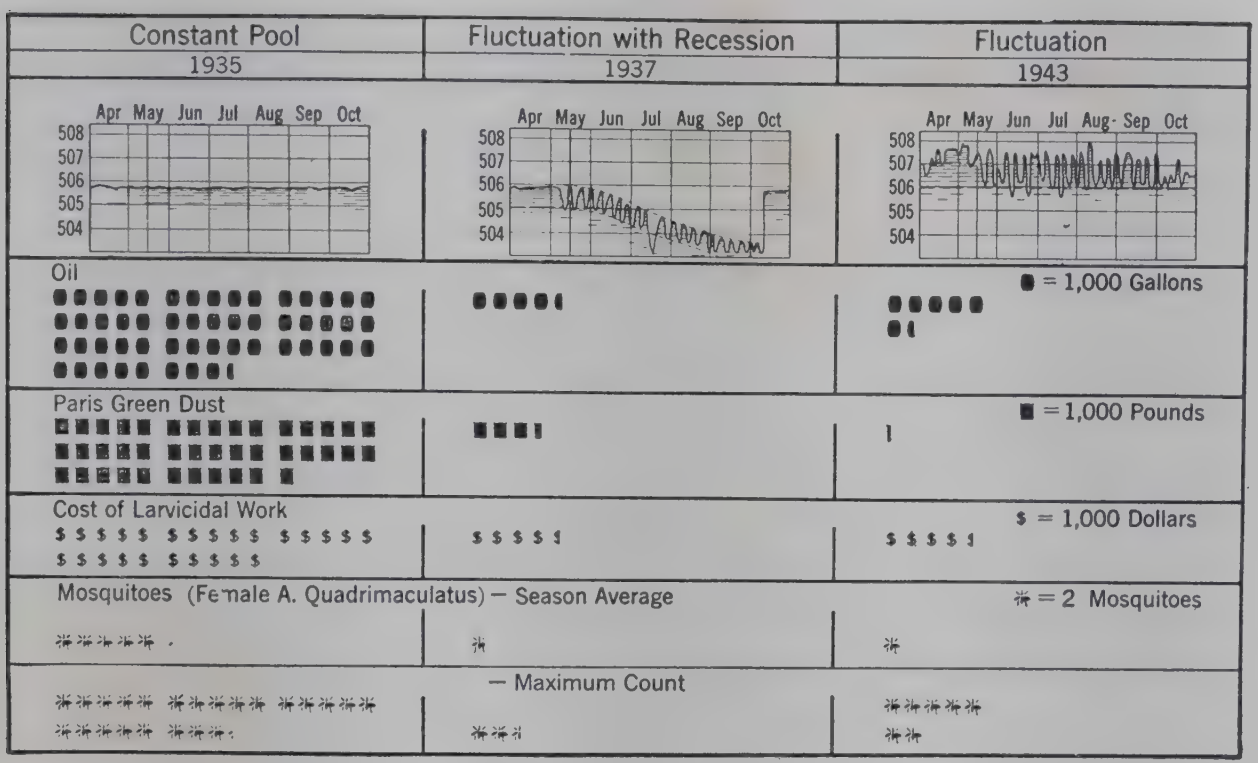

FIGURE 57.—Comparison of three types of water level management schedules Wilson Reservoir, Tennessee River.

age maintenance. These measures are discussed in detail in chapters III and IV.

Figures 57 and 58 have been taken from records of experiences with various types of water level schedules of reservoirs on the Tennessee River. These charts show that the most difficult and expensive mosquito control problems are encountered with a constant level or slowly filling reservoir. Further, they show that water

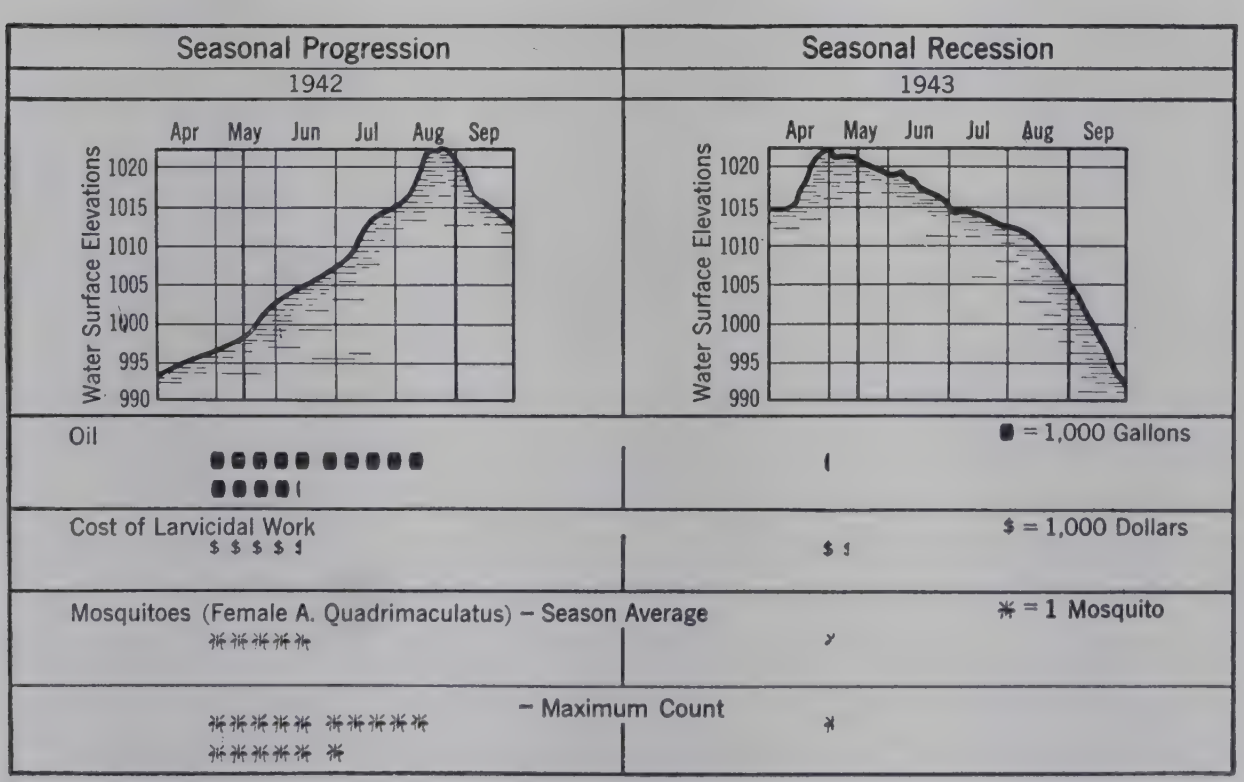

FIGURE 58.—Comparison of seasonal progression with seasonal recession (Reservoir cleared to El. 1020) Norris Reservoir, Tennessee.

level recession alone can be very effective in a properly cleared reservoir of fairly steep topography. It may also be noted that there is little difference between periodic fluctuation combined with seasonal recession and wider periodic fluctuation without recession in run-of-river reservoirs on the basis of cost and effectiveness.

It is well to bear in mind that water level recession is a feature which can be scheduled with greater certainty on most projects than periodic fluctuation, provided the reservoir is filled by the beginning of the season and there are adequate water control structures at the dam. Where normal uses require a recession in excess of mosquito control needs, a progressively clean shore line will prevail with accompanying improvement in mosquito control, but the resulting increased growth invasion may require additional growth removal operations before the next season.

Water level recession without periodic fluctuation would be the principal feature of water level management for mosquito control in the average storage reservoir. Inasmuch as storage reservoirs usually have steep shore lines of relatively low soil fertility, wider departure from scheduled water levels can be accepted.

PLANNING WATER-LEVEL MANAGEMENT SCHEDULES

Water-level management for mosquito control should be considered in the initial planning of an impounded water project. In developing water-level management schedules, a realistic and practical approach should be used to fit them into the normal uses of the project. It must be remembered that every project has certain water-level schedules which are necessary to meet its primary objective, whether it be for power development, flood control, navigation, water supply, irrigation, recreation, wildlife conservation, or any combination of these; but frequently a water-level schedule suitable for mosquito control can be planned without significant disadvantages to the primary function of the project. Occasionally there are direct conflicts which may tax the resourcefulness of those responsible to devise an effective malaria control program under conditions of adverse water-level schedules. Where adequate mosquito control is not in prospect through water-level management, it may be necessary to consider other measures, such as permanent shore line improvement, land-use restriction, mosquito-proofing, house-spraying, etc., which are discussed in other chapters. The important thing is that the malaria control program be planned as a part of the over-all development, with a view of providing as favorable water-level management for mosquito control as the project and circumstance will permit.

There are many factors which should be taken into account in planning water-level management schedules for mosquito control on impounded water. These schedules will influence reservoir preparation and the total malaria control program. Hence, they should be developed in the planning of malaria control measures. Some of the features may be fixed by the design of the dam and the normal operating schedules. Others involve the establishment of facts relating to such matters as stream flow predictions, size of reservoir, character of marginal growth, the beginning of the growing season, and the average dates of the beginning and ending of the anopheline mosquito-breeding season. Before final adoption, water schedules should be studied for effectiveness, relation to normal operating requirements, economic considerations, bearing on shore-line maintenance and larviciding, effect of other interests, such as wildlife conservation, etc.

Those planning water-level management schedules for mosquito control should utilize all of the available factual information to the fullest extent. Primary objectives of the project should be analyzed with a view of fitting mosquito control needs into the normal operating schedules. If all the desirable features for mosquito control cannot be obtained, then supplementary measures should be planned, utilizing such water-level management features as can be provided. It is especially important to analyze the stream flow and other data, working with the design engineers to be sure that the water-level management schedules for mosquito control are practical and possible of attainment.

The first step in planning a schedule is to determine all the limiting facts regarding stream flow and project design. Stream flow data over a period of years should be obtained so that maximum and minimum water levels, as well as the frequency of their occurrence, may be predicted. Designers should supply the normal operating schedules desired for meeting the objectives of the project under these varying conditions. *It is especially important that a maximum "mosquito-control" elevation be established because it will be the reference line for reservoir preparation, reservoir maintenance, and water-level management.* Other important elevations are the maximum and minimum elevations expected, particularly during the growing season. Information of this character should be graphed as far as possible over the full 12 months of the year, and for various anticipated frequencies over a period of years.

On hydroelectric projects, turbine and spillway gate discharge capacities should be ascertained so that these data may be correlated with the inflow and storage in establishing the limiting rates of

filling and draw-down for the reservoir. Occasionally, projects are encountered where water releases at the dam are fixed within limits in the interest of such considerations as flood control, navigation, irrigation, stream sanitation, or domestic and industrial water supply uses. These requirements must be considered in the development of the water-level management schedules for mosquito control in the reservoir.

In submitting information on the normal operating schedules, designing engineers should distinguish between essential features and those where some latitude would be permissible. For instance, navigation requirements may not permit drawing the lake down at any time below a given fixed elevation. This is definitely a "must" and would be so considered in planning water-level management schedules for mosquito control. On the other hand, it might not be objectionable to vary the initiation of the release of stored water at the beginning of the dry season as much as 30 days. This latitude would permit a more favorable adjustment to the seasonal variation of beginning recession for mosquito control.

In studying water-level management needs for an individual reservoir, it is most important to establish basic facts regarding the anopheline vector in the region and the environment in which it is produced. This would pertain particularly to the seasonal beginning and ending of mosquito production and the character of the marginal plants occupying or likely to colonize the lake margins over a period of years. Considerable variation in the average time of the beginning of adult mosquito emergence may be encountered at different latitudes and altitudes. (See fig. 158.) For instance, in the most southerly portion of the Tennessee River at an approximate elevation of 500 feet significant emergence of *A. quadrimaculatus* begins normally between May 1 and 15, while only 100 miles farther north at an elevation of 1,000 to 1,500 feet, the average beginning is 4 to 6 weeks later.

Since water-level management schedules should be designed to minimize the marginal growth problem as well as to limit anopheline mosquito breeding directly, it is important to establish the character of the plant growth in the reservoir. Plant surveys should be made each year after impoundage, in addition to the preimpoundage surveys, since plant populations are not static. The species of marginal plants, their location in the zone of water-level variation, their physical properties, time of fruiting, method of propagation, etc., are of interest in planning water-level management schedules.

In assembling factual information to be used in planning water-level management schedules for mosquito control, it would be

advisable to consult with persons representing wildlife conservation and recreational interests. An increasing incidental use of impounded water projects for these purposes is being made in the United States, and some projects are being impounded primarily for such uses. In any event, water-level schedules for mosquito control should be planned with a view of favoring these purposes when possible. In recent years it has developed that many features of water-level management for mosquito control are of benefit in wildlife conservation. A discussion of these features and other mutual interests between malaria control and wildlife conservation will be found in chapter XIV.

On a chain of reservoirs it is necessary to consider the water-level management schedule on each reservoir in light of its effect on the impoundages downstream. This is especially true with regard to periodic water-level fluctuation. Obviously, if a reservoir of 25,000 acres is lowered 1 foot on a weekly cycle of periodic fluctuation, it would create only a 6-inch rise in a 50,000-acre reservoir located next in the chain, assuming similar topography. A chain development has advantages of flexibility, but wide variation in reservoir sizes, generating capacities, etc., present a considerable operating problem in working out the most advantageous schedules within the limits of the individual projects.

OPERATIONAL CONSIDERATIONS

In applying water-level management for mosquito control on impounded water, it is important to provide for current collection and analysis of pertinent information. This would include such information as the results of adult mosquito station collections and of dipping for larvae. Especially important is provision to obtain periodic observations on the extent of marginal growth invasion considered significant in mosquito production. This may be done by establishing transect lines of stakes at about 6-inch contour intervals in typical areas for convenience in reading the lower limit of the growth invasion. Also, there should be provision for daily water elevation readings and, if possible, progressive forecasts as to future elevations several days in advance. This information should be plotted currently on a progress chart. A typical chart of this type for a season's operations on a Tennessee River reservoir is shown in figure 59.

Progress charts are especially useful in consulting with operating officials when it is necessary to make departures from normal water-level schedules. Compromises, decisions as to alternative procedures, and establishment of the time of initiating the various phases of

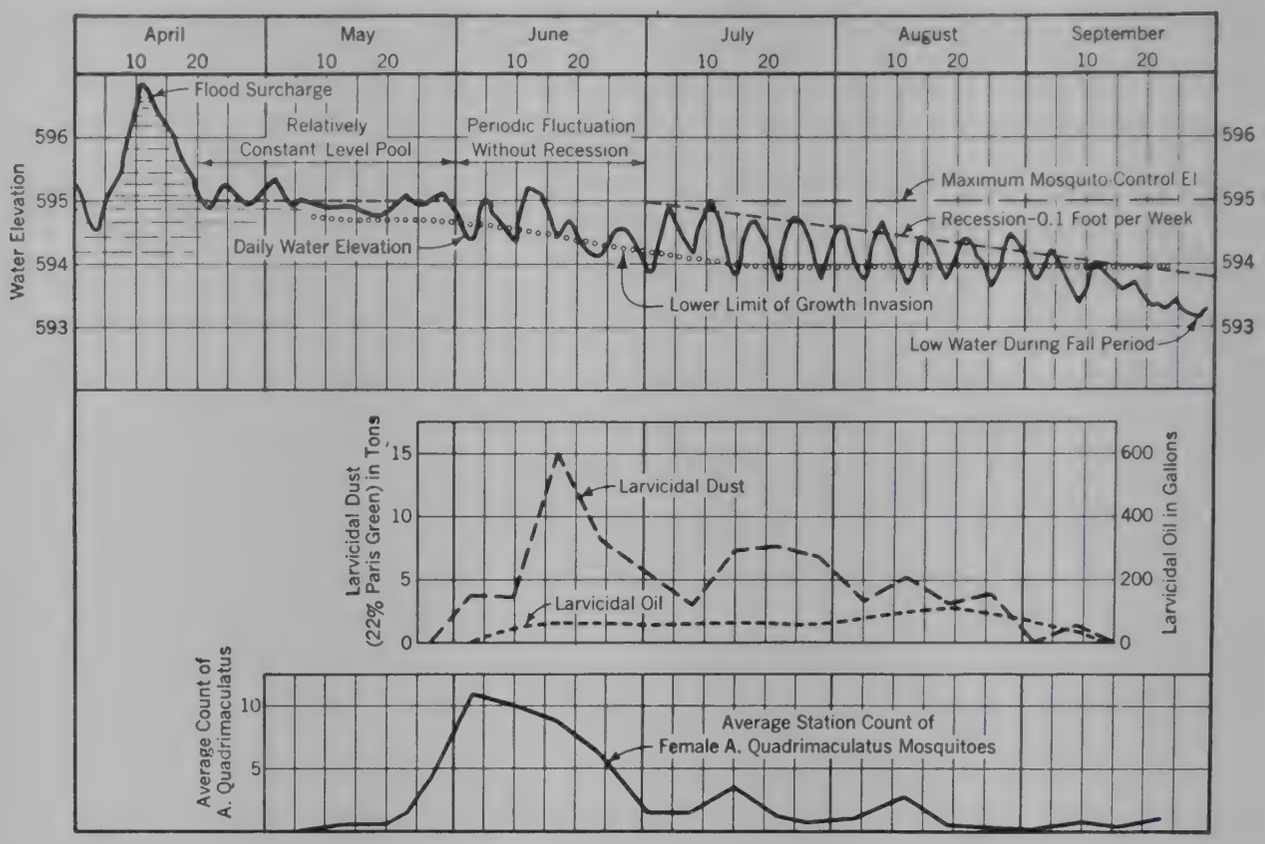

FIGURE 59.—Typical progress graph of water-level management.

water-level management can be made largely from information shown on the graph. The maintenance of such progress charts over a period of years provides a record which is useful in planning future schedules on a reservoir in question, as well as others of similar character.

It is rarely possible to follow a planned schedule of water-level management exactly throughout an entire season. This is due to the many unforeseen exigencies which may develop, such as wide variations in stream flow, flood control operations, variations in the beginning of the growing season, the beginning of significant mosquito production, etc. Each departure should be appraised as to its consequences, both temporary and over a period of a season or longer. All departures are not equally objectionable; hence, each should be appraised individually for its effect on the program as a whole. They may be so serious that the entire schedule for the remainder of the season must be altered in compensation, or they may be of only temporary importance. Malaria control personnel should work very closely with reservoir operating officials in dealing with these exigencies. Specific responsibilities to provide malaria control protection should be met in the most economical way with a minimum of interference with the primary objectives of the development. Difficulties may sometimes be encountered when persons representing separate interests insist, without compromise to the over-all interest, on a water-level management practice most

favorable to their particular program. A cooperative viewpoint should be taken by all concerned with operation of an impoundage. Economic considerations should always be taken into account; hence, data should be available for making a choice between alternate measures on the basis of costs as well as effectiveness.

Spillage of water on hydroelectric projects, with consequent losses in power generally, is to be avoided if possible. However, situations may arise where this is necessary to provide adequate mosquito control. Other situations may be encountered where spillage can be avoided by using emergency malaria control measures. In some instances, spillage may cost less than an increased larvicidal program. Difficult mosquito control situations arising from temporary high water levels may be met by extensive use of larvicides, house-spraying, or other emergency measures. An incidental benefit may result in the future through the limitation of marginal growth by this temporary flooding.

ADVERSE WATER-LEVEL MANAGEMENT PRACTICES

There are some water-level management practices which are undesirable on major impoundages where malaria control is being sought through use of conventional mosquito control measures. Particularly adverse practices are (1) the utilization of the uncleared zone for storing water for a sustained period during the summer for flood control or the development of power, and (2) the practice of drawing the water down during the spring and early summer, and thus exposing the margins to excessive plant invasion

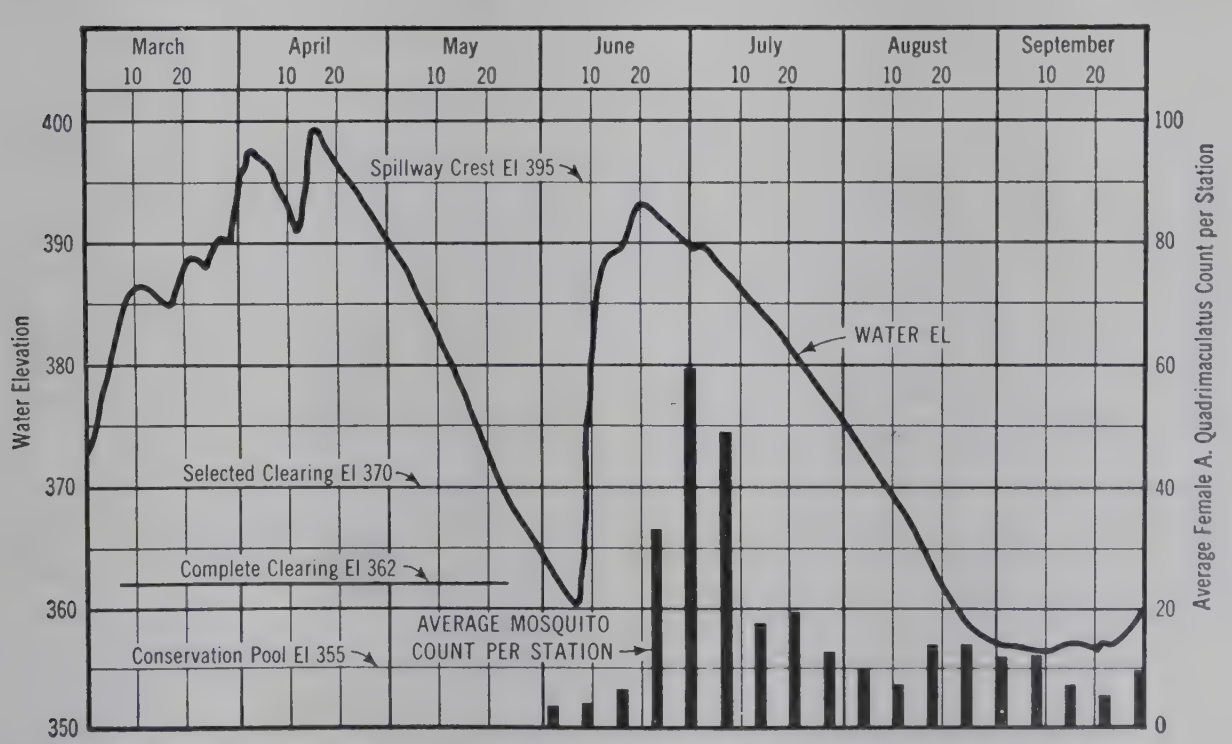

FIGURE 60.—Increase of mosquito production as a result of summertime filling of a flood control reservoir above the clearing line—Wappapello Reservoir, Missouri (1945).

with the intention of refilling later during the season, and holding the level up in the vegetation indefinitely for water usage. Excessive mosquito production will occur in the normal run-of-river reservoirs under these conditions, and cannot be controlled with present conventional antilarval measures. Of course, the practices may be acceptable if other adequate malaria prevention measures, such as land-use restriction and permanent shore-line improvement, have been planned to meet adverse water-level schedules.

In some projects, for one reason or another, water-level management favorable to mosquito control is not feasible or consistent with the primary purposes of the development. Typical of such projects are old reservoirs where water-level management for mosquito control was not provided for in the original plan. Other projects call for a constant level pool as in some recreational projects, water supply reservoirs, and fish ponds. Then there are those where filling may normally be required during the mosquito season, as in the case of flood-control reservoirs where floods are caught during the summer with subsequent slow release of the water. An example of summertime filling of a flood-control reservoir with attendant increase of mosquito production in absence of larviciding is illustrated in figure 60. It may be noted that mosquito production rapidly decreased upon initiation of a sharp recession, even though the water level was above the clearing line. However, it should be remembered that recession alone for controlling mosquito production is fully effective only in cleared reservoirs in relatively steep terrain.

Assuming that the merits of the project warrant a water-level schedule unsuitable or inadequate for mosquito control, those responsible for the malaria control program must nevertheless devise a plan to provide adequate protection of the adjacent population. If the project is an old one on which a favorable water-level schedule cannot be obtained, then special emphasis should be placed on other antilarval measures, such as removal of marginal growth, use of larvicides, drift removal, and application of herbicides. Other measures, such as house-spraying, mosquito-proofing and land-use restriction, may also have application.

On small constant level projects, such as water supply reservoirs, fish ponds, etc., it may be practical to minimize anopheline production by frequent shore line cleaning during the season. This excepts unfavorable flat topography which might be modified by deepening or filling the shallow areas, as a preimpoundage measure. Situations may be found where alternative choices in dam sites or normal water elevations can be made in the interests of minimizing shallow mosquito problem areas along the margins of the reservoir.

On new projects the owner or managing official should be given a frank appraisal of the situation, with recommendations of what will be required and the cost involved in providing adequate malaria control protection under the adverse water-level schedule anticipated. In reservoirs of very flat topography where antilarval measures would be unduly expensive or ineffective and house mosquito-proofing or spraying could not be employed for one reason or another, then one or more of the permanent approaches should be considered, such as minor shore line topography alteration, deepening and filling, diking and dewatering, or land-use restriction to daytime occupancy of zones within mosquito flight range. All of these measures have been used heretofore on impounded water projects, and their utility and practicability have been demonstrated.

VI. SHORE-LINE MAINTENANCE

GENERAL CONSIDERATIONS

The discussions in previous chapters establish reservoir preparation and water-level management as essential factors in the prevention of anopheline breeding on impounded water. Despite careful reservoir preparation and planned water-level management schedules, provisions must be made for the annual maintenance of the zone of potential anopheline production during the postimpoundage period. The principal objective of this maintenance is to eliminate or minimize plants or plant parts which would create favorable conditions for the production of anopheline mosquitoes. The shore-line maintenance operations through which this objective may be accomplished are outlined as follows:

I. Marginal growth removal.
    A. Area growth removal (nonselective).
        1. Mowing
        2. Area burning
        3. Hand removal
    B. Woody growth removal (selective).
        1. Hand removal
        2. Arboricidal treatment
II. Marginal grazing
III. Drift removal.
IV. Ditch maintenance.
V. Aquatic growth control.
    A. Mechanical control.
    B. Herbicidal treatment.
VI. Minor shore-line topography alteration.

The extent and nature of shore-line maintenance operations are intimately related to the water-level schedules of the reservoir, plant types in the watershed, topography of the basin, types of soils, and the age of the reservoir. Typical zonation of terrestrial, wetland, and aquatic herbs along the margin of a newly impounded reservoir does not become established until after several seasons. For example, annuals, such as smartweed or wild millet, and woody species, such as willow and buttonball, may be produced in profusion the first season; red-top panic grass requires about 3 years to develop into dense marginal bands; and significant stands of water willow weed usually do not develop until a reservoir is about 7 years old. In reser-

voirs with limited recession and fluctuation of the pool water level, schedules can be used to manage effectively most plants in the main marginal band of vegetation. Proper water-level management may be used to limit the invasion of marginal plants, and to promote the development of the less objectionable wetland flexuous types in place of the more objectionable woody species and stiff-stemmed herbs. Most deep water emergent aquatics are, however, not effectively controlled by water-level management, and without proper vigilance may greatly increase anopheline breeding areas and necessitate costly maintenance operations.

The time when shore-line maintenance operations are carried out depends upon the type of operation and the seasonal water-level schedule of the reservoir. Marginal growth removal can usually be carried out best in the fall and early winter after killing frosts have stopped plant growth and when the water level is low. The successful use of running fires is particularly dependent upon the occurrence of heavy killing frosts and favorable burning weather. Minor alteration of shore-line topography is also best carried out in the dry, fall period when the reservoir level is low. Grazing and aquatic growth control are most effective if done during the growing season when plant activity is the greatest. Drift removal and ditch maintenance may be carried out any time during the year, but should usually be done in the fall in conjunction with other maintenance activities.

MARGINAL GROWTH REMOVAL

The objective of marginal growth removal is to remove from the zone of fiuctuation the season's accumulation of herbaceous and woody growth which would otherwise persist through the winter months and create favorable mosquito-breeding conditions the following spring. The operation may involve either the selective removal of woody growth or the nonselective removal of all growth on an area basis. In either case, the most important feature is the removal of the erect stems of water tolerant coppice or the persistent aerial stems of herbs. The reasons for this are as follows:

1. These plants remain erect over the winter months, intersect the water surface, collect drift and flotage and prevent its stranding, and function as wave breaks, thereby creating a favorable habitat for anopheline larvae during the ensuing season.

2. Coppice becomes increasingly rank, develops a closed canopy, practically eliminates flexuous herbs, and, thereby, prevents the use of fire as a "tool" in shore-line growth control.

3. The aerial portions of the plants serve as mechanical barriers to decrease the efficiency of larvicidal operations.

The effectiveness of marginal growth removal in creating and maintaining a maximum of clean water surface during the following mosquito-breeding season is clearly illustrated in figure 61. Note particularly the survival of water tolerant coppice of black willow in the unconditioned area. A comparison of the densities of anopheline larvae produced in conditioned and unconditioned areas of this type is given in figure 62. Mosquito production in the area from which marginal growth has been removed is limited to the shallow water in the upper few inches of the zone, while mosquito production in the unconditioned area extends throughout the zone of fluctuation. It is evident that cyclical fluctuation for mosquito control would be quite effective in the conditioned area but would be relatively ineffective in the unconditioned area.

The method of marginal growth removal used will be dictated by the types of plants prevalent and the water-level schedule employed on the reservoir. In considering the method to be used, emphasis should be placed on the removal of coppice and stiff-stemmed herbs rather than those species which will dissipate during the winter months. The method selected should also be one which, in con-

FIGURE 61.—Comparison of an area from which marginal growth has been removed with one which was left unconditioned, illustrating typical conditions in the late spring at the end of the constant pool phase of water-level management just before the initiation of cyclical fluctuation.

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junction with proper water-level management, will tend to eliminate objectionable species as much as possible. For example, along margins colonized mainly by flexuous herbs interspersed with water-tolerant coppice, it would be preferable to eliminate the coppice by cutting below the root crowns, by arboricidal treatment, or by area burning rather than by "block" conditioning of entire areas by mowing. On the other hand, in an area colonized by dense stands of stiff-stemmed herbs and seedlings of water-tolerant, woody species, area mowing or conditioning would be indicated where water level schedules provide for a full pool during the first part of the following growing season.

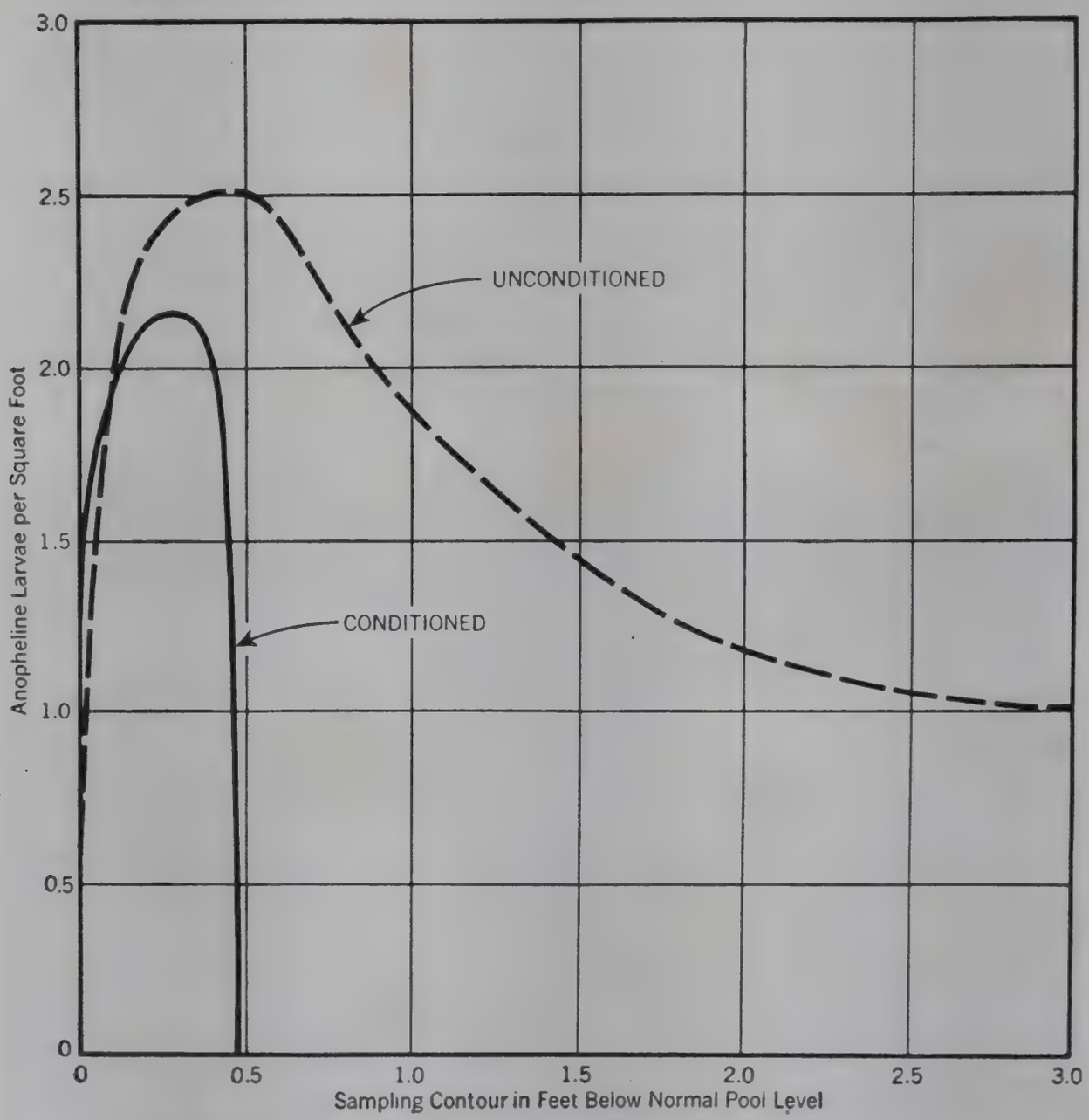


FIGURE 62.—Effect of marginal growth removal upon anopheline mosquito production during the following season in a situation similar to that illustrated in figure 61.

Area growth removal

Mowing—Mowing by either tractor or horse-drawn equipment (see fig. 63) is carried out principally in areas containing a predomi-

FIGURE 63.—Marginal growth removal with a team mower.

nance of erect stiff-stemmed herbs, seedlings, or switch coppice of water tolerant woody species. Mowing machines are not effective against heavy coppice, and in these types of situations the coppice must be cut by hand before mowing.

For mowing small isolated areas it is advantageous to contract for the services of equipment and driver from local farmers. Where large acreages are involved it will usually be advisable to purchase mowing equipment and carry out the operation under direct supervision. Mowing equipment purchased for use in shore-line maintenance operations should include a heavy-duty blade and guard. Spare parts should be stocked to facilitate repair operations.

Of the two types of mowers, the purchase of tractor equipment is preferable. The economy is apparent through:

1. Elimination of the need for obtaining, feeding, and caring for teams in isolated areas.

2. Greater ease of transportation by barge or over long hauls by truck.

3. Increased progress due to greater speed and ability to cut heavier sprouts.

The disadvantages of tractor over team mowing are the relative lack of maneuverability and inability to work boggy areas.

Running fires are frequently used to dispose of mowed vegetation after it has dried for a sufficient period to carry the fire. In some situations, particularly those with considerable woody growth, the cut plants are piled or windrowed before burning. As a general rule, however, if the material is too scattered to carry a running fire, it is left on the ground without further treatment.

Low-stumping greatly facilitates the carrying out of mowing operations and for this reason is a recommended procedure in reservoir preparation. (See ch. III.) In some situations where low-stumping was not carried out during reservoir preparation, it may be justifiable to perform this operation as a postimpoundage measure to permit area mowing.

Area burning—Where conditions permit its use, controlled area burning is an effective and economical means of marginal growth removal. It is particularly useful as a "tool" for controlling seedlings and small coppice of water tolerant species, such as black willow, where these woody plants are interspersed with flexuous species capable of carrying the fire. With water-level schedules of limited recession, running fires will not only control coppice but also will favor the growth of flexuous herbs, such as smartweed, millet, rice cutgrass, and panic grass, which will make possible the continued use of area burning during subsequent seasons. The main advantages of area burning over hand and machine removal are the rapidity and

FIGURE 64.—Area burning operations showing firebreak and firefighting spray equipment.

economy of the operation and its effectiveness in controlling woody species and in removing objectionable stiff-stemmed plants. Where these types of plants are absent, area burning appears to be of minor value since most flexuous herbs are usually dissipated over the winter months. Experience indicates that in the interest of economy, area burning should be limited to sizable tracts (5 acres or more per mile); otherwise, the costs for fire trails may become excessive as compared with alternative measures.

The successful utilization of area burning depends upon the season of the year, the fuel-moisture content of the vegetation, the volume of rough, and general weather conditions. The operation is usually carried out most effectively after repeated killing frosts. Obviously, burning may best be carried out during periods of low lake levels. Where water schedules permit, the operation should be deferred until February or March or just prior to the beginning of the next growing season. Experienced field workers usually can judge when weather conditions are suitable for burning and when the vegetation has the proper fuel-moisture content and a suitable volume or density for burning. The fuel-moisture content of cured vegetation is determined by the combined effects of the temperature, humidity, evaporation, and wind, and may be approximated by means of a fuel-moisture indicator stick. In vegetation with the proper fuel-moisture content, the operation may usually be carried out best with low, steady winds (about 5 miles per hour) during periods of relatively low humidity. Steady winds are most suitable for area burning because they (1) accelerate combustion by increasing the oxygen supply, (2) drive the heat and flames laterally instead of upward, and (3) carry the sparks and embers ahead.

Rapid ignition of marginal growth can be accomplished with a kerosene-burning torch (fig. 66) carried by one man. The convection currents developed in rapidly fired areas promote the complete removal of "rough" while tending to draw the fire away from bordering uplands. Figure 64 indicates the method of firing a marginal zone with a properly prepared firebreak.

Probably over 90 percent of the time and money spent on area burning is for precautionary measures to confine the fire to conditioning areas. Bordering forest lands, lespedeza fields, broomsedge fields, etc., are often highly combustible, making the operation a hazardous one. Firebreaks with widths varying from 6 feet along damp hardwood forests to 20 feet along dry upland forests are of the utmost importance in burning operations. Firebreaks can be chopped out by hand with swinging blades, mowed and raked by teams, or constructed with a disk plow drawn by a caterpillar trac-

tor (fig. 65). A firebreak made with a disk plow is quite effective and, in itself, will usually prevent running fires from escaping. Such firebreaks are generally preferred to hand and mower-made trails as the latter require constant attention to prevent the fire from jumping the firebreak. In the event a fire should escape across a

FIGURE 65.—Disk plow cutting a firebreak.

trail, it is imperative to have sufficient men and equipment immediately available to check its spread. Men engaged in area burning should be carefully instructed in the importance of their individual duties, and be made aware that inattention on the part of any one man may mean hours of hard, dangerous work for the whole crew and that an uncontrolled fire might result in considerable damage to bordering uplands. Equipment used for lighting and controlling fires is shown in figure 66.

Hand removal—The use of hand operations is the most expensive method of marginal growth removal. However, in small, rough, or inaccessible areas, where machine equipment cannot be used or where the vegetation is of a type which will not carry a running fire, it will be necessary to use hand removal. The efficiency of the operation will be considerably improved by the use of proper types of tools selected for the particular job at hand. A great variety of hand tools are available which are suitable for hand growth-removal operations. The tool selected for a given operation should be: (1) lightweight but suitable for both heavy and light material; (2) easy to assemble, sharpen, transport, pack, store, and repair; and (3)

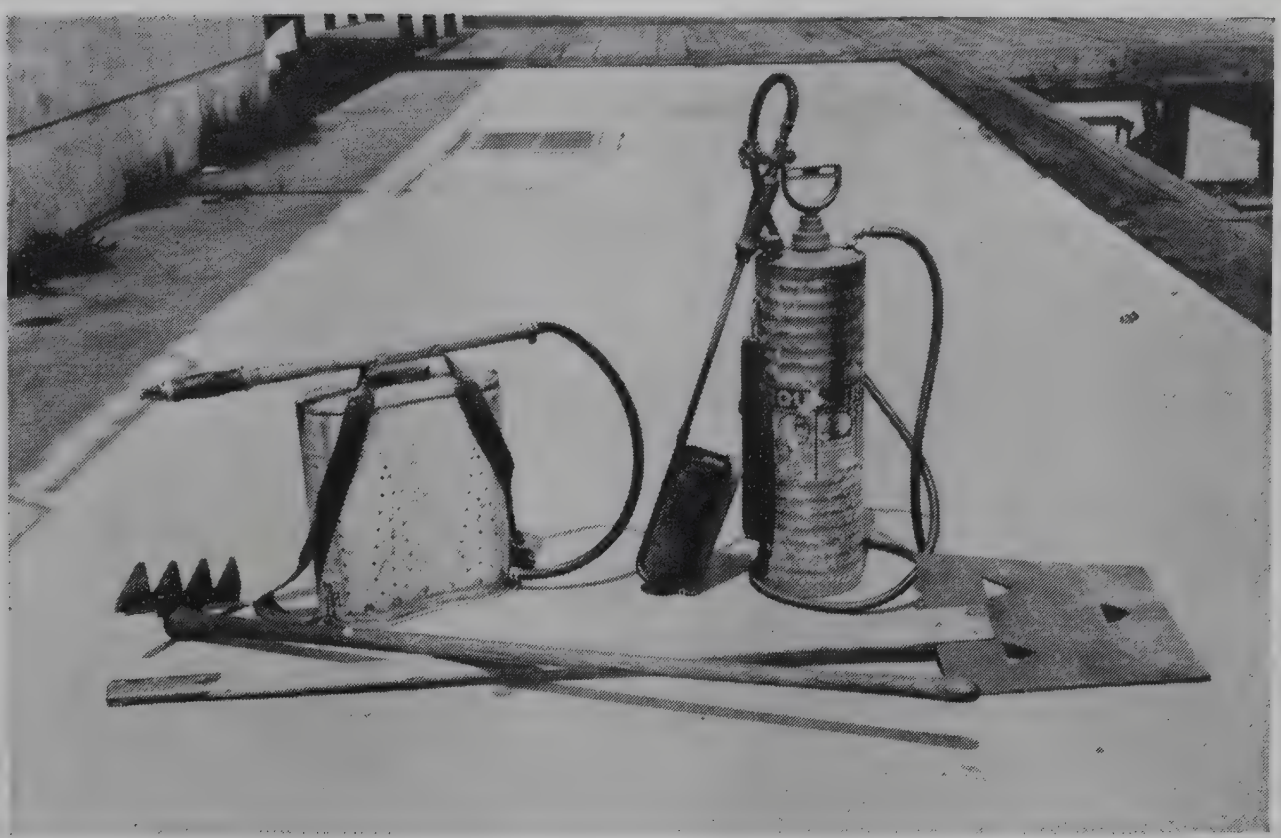


FIGURE 66.—Kerosene-burning torch, water spray can, fire rake, and fire flap used in area burning operations.

safe to use. Among tools that can be used are single- and double-bitted axes and bush hooks, and a number of swinging tools, such as the scythe axe, Kelly blade, jumbo cutter, and mower-tooth rakes (fig. 67). The double-blade bush hook is a superior tool for "cutting below the root crown" and for "scalping" techniques. (See section on "Woody growth removal.") In rocky terrain where work of this nature is rather limited, the use of old tools is recommended, thus preventing nicking, hardening, or otherwise damaging regular tools. Obviously, tools should be sharp, maintained in good repair, and adequate tool replacement should be available on the job.

The size of the labor force necessary for hand operations is determined by the extent of the area to be conditioned, acreage per unit of shore line, accessibility, and character and density of the growth. For average run-of-river reservoirs a crew of 15 laborers, a tool filer, and a foreman is desirable for shore-line conditioning from the standpoint of progress and cost. On long and relatively narrow shore lines it may be necessary to make some adjustments in the size of force in order to prevent the laborers from becoming excessively scattered. In field operations the men should be reasonably well scattered to permit free swinging of cutting tools, thereby assuring greater safety and efficiency.

Woody growth removal

The removal and control of water-tolerant woody species is the

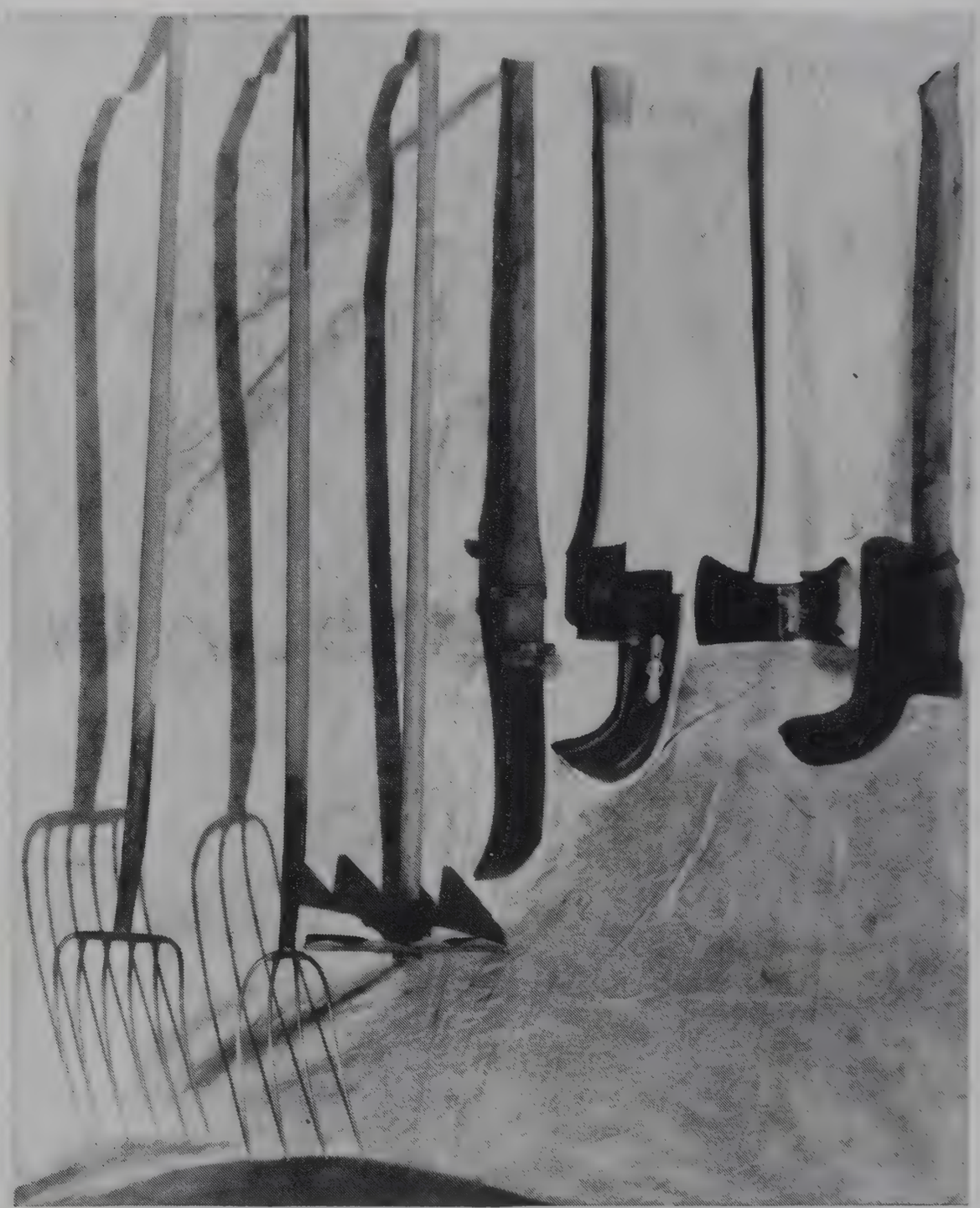


FIGURE 67.—Tools used for hand removal of growth.

most important element of marginal growth-removal operations. The development of marginal herbs in the zone of fluctuation can be minimized through the use of controlled water level schedules, and, in the most favorable situations, the need for annual removal of these species may be entirely eliminated. In contrast, when water-tolerant, woody species become established in the zone of fluctuation, it is impossible to control them by water-level management. As long as portions of their stems protrude above the water surface they will continue to grow, and will greatly extend the potential mosquito-breeding area. Also, they will "shade out" the relatively unobjectionable flexuous herbs and, thereby, prevent the effective use of area burning. The removal and control of coppice and seed-

lings of water-tolerant, woody species should therefore receive primary attention in shore-line maintenance operations. Two types of control measures are available: (1) hand removal; and (2) application of arboricides.

Hand removal—Hand removal of woody species may be directed either at seedlings or at coppice (sprouts from stumps or stubble). Seedlings of black willow usually become established in the fluctuation zone on abandoned agriculture fields and silt banks where competition is meager. Although the major crop of willow seedlings can be excluded from the fluctuation zone by maintaining a full pool elevation when seeds are deposited, the complete exclusion of willow seedlings cannot always be realized, particularly in flood control reservoirs. Some willow seedlings may inadvertently become established in the fluctuation zone as a result of unfavorable water levels or by secondary seed crops and, thereby, create a maintenance problem. Cutting willow seedlings below the root crowns the first year frequently is not practical because of their great density (often over 100,000 per acre). The best practice is to mow the "seedlings" in order that their density may be reduced the following season by flooding the stubble or by competition with herbaceous species. However, after two or three seasons' mowing, the stubble becomes large and gnarled making further mowing impractical and, thereafter, requires the application of a different conditioning technique. The best method for controlling the thinned, gnarled stubble of previously mowed willows appears to be cutting them below the root crowns (just below the ground line) as shown in figure 68. This technique does not add excessively to the cost of hand removal, and when applied progressively it will eliminate the need for repetitive annual coppice control of young stock. Cutting below the root crowns should be used only on those woody species which do not produce leafy shoots from the roots. Most woody species in the fluctuation zone fall into this category, but well-known exceptions are sandbar willow *(Salix interior)* and persimmon.

Hand cutting which leaves relatively high stubble may be justified in the case of terrestrial species, but in the case of seedlings of woody plants and water-tolerant coppice it will be better and more economical over a period of time to use a measure which will eliminate or kill the plants. Simply cutting these plants above the ground may actually make shore-line conditions worse rather than improve them. For example, when stubble of water-tolerant species, such as willow, is allowed to sprout, it often produces 10 to 20 leafy shoots which provide much higher intersection values when partially flooded than the single stem of uncut specimens.

Scalping is a special method for removing coppice from stumps. It consists of cutting the sprout close into the stump so as to remove the "eye" of the sprout. Stumps in a properly prepared reservoir are cut flush with the ground in anticipated mosquito-breeding problem areas. Scalping coppice on such flush-cut stumps has a definite value in preventing sprouting and in retarding subsequent coppice growth as it extends the total period the stump will be submerged. It will be observed in figure 69 that coppice from stumps dewatered during the latter part of May will attain about 90 percent of the total height attained during a complete growing season, whereas it will attain only about 12 percent of the total seasonal height if the initiation of growth is deferred by flooding until the

FIGURE 68.—Cutting woody sprouts below the root crown.

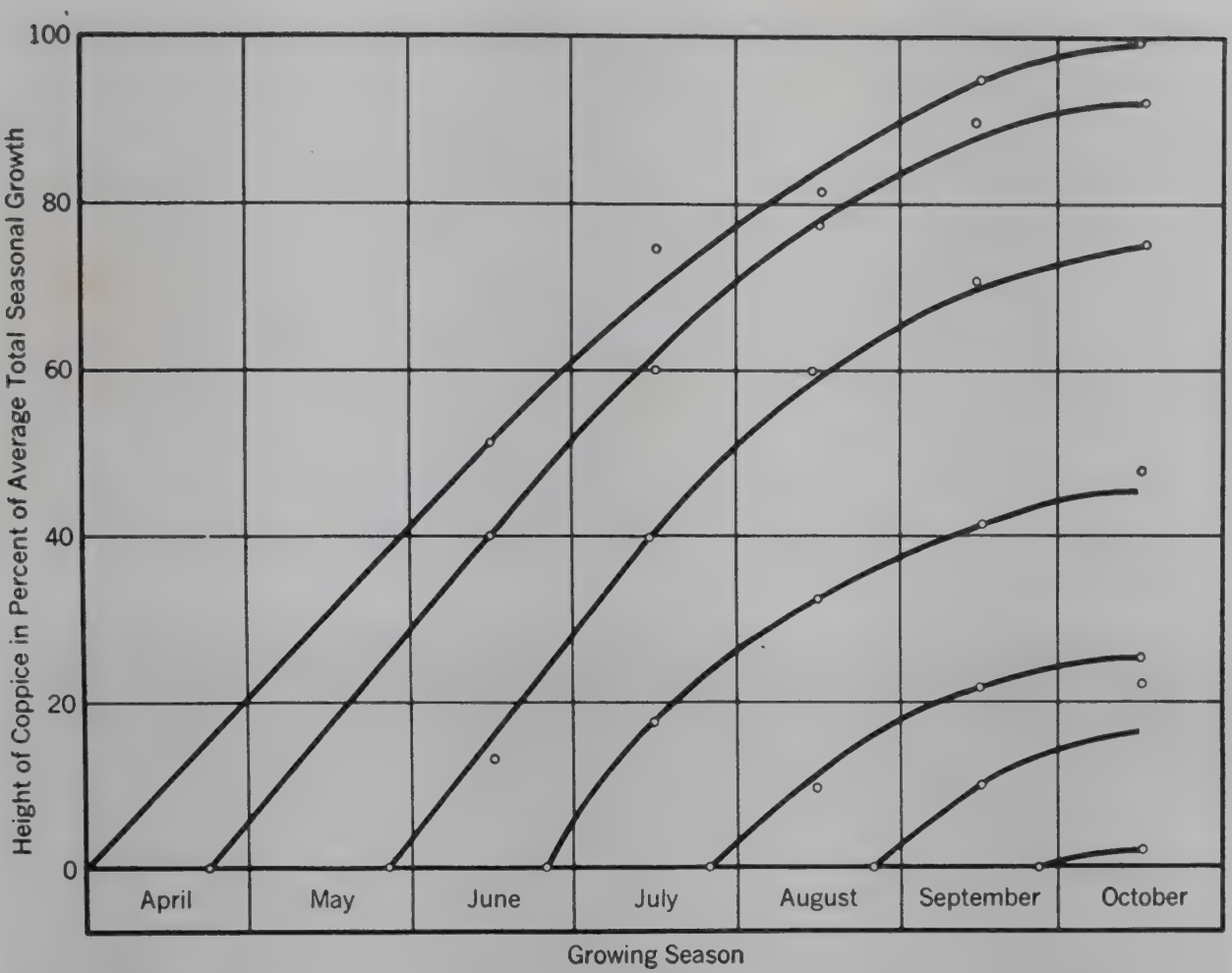


FIGURE 69.—Growth of coppice following cutting or dewatering at various intervals during the growing season in the Tennessee Valley.

latter part of August. Scalping and subsequent flooding may therefore be used to eliminate and control coppice and to promote the growth of flexuous species by lessening competition due to coppice. Tender dwarf coppice produced from stumps of water-tolerant species not dewatered until later in the season can be controlled by the use of running fire.

When heavy stands of coppice are cut, the brush should be piled with the butt ends of the growth in the center of the pile. Willows cut in moist areas should be piled and fired as the cut stems are able to take root and give rise to new colonies vegetatively.

A hay rake may be used to advantage for windrowing lighter material. A 9-foot, self-dumping, team-drawn rake, having every other tooth removed, is capable of passing around or springing over most obstructions encountered.

Ideal weather for burning brush piles is relatively rare, but efforts should be made to select the best days available. Burning should not be deferred too far behind the conditioning operations since men may be needed in the general area as a precaution against fire spreading to adjoining territory. Mild, dry weather is preferable to days with gusty winds which tend to singe rather than consume the brush and add to the fire hazard in marginal timber. Firing of brush

piles and windrows may be accomplished with a "fire mop" or with a kerosene-burning torch. A fire mop is a small can filled with kerosene-soaked rags fastened in an upright position on the end of a mop handle. A typical weed burner consists of a portable pressure tank with a hose and nozzle from which a flame of blue heat can be obtained. This equipment operates most satisfactorily with kerosene fed at a rate of 5 gallons per hour of operation. Such a weed burner is quite effective for burning damp or green brush piles. The torch should be directed into the pile until the brush reaches the kindling point. In areas with sufficient carrier vegetation, scattered cut coppice may be disposed of by area burning without piling or windrowing.

FIGURE 70.—Low stumping with a motor-driven saw.

Recent developments indicate that hormone types of sprays, such as 2,4-d, will effectively control willow coppice. In the future, the use of these new types of herbicides may well supplant the repetitive mechanical methods for controlling woody species as discussed above.

Arboricidal treatment—As previously discussed, the sprouting of water-tolerant stumps in the upper part of the growth invasion zone often creates a difficult maintenance problem. Stumps of black willow and green ash usually can be killed by continuously flooding the top of the stump from the beginning of the growing season until about June 15 but stumps of buttonball will usually sprout when dewatered any time during the growing season. Cutting sprouts below the root crown is usually limited to seedlings and saplings

having a butt diameter of 2 inches or smaller. Grubbing of larger stumps can be carried out without subsequent sprouting but is not practical. For control of water-tolerant stumps larger than 2 inches, an arboricidal treatment which will prevent further sprouting is recommended. Experiences on large-scale arboricidal operations indicate that preparation of the stump is more important than the particular arboricide used. High stumps may be prepared for arboricidal treatment either by completely girdling or frilling the stump or by cutting it flush with the ground. The latter method is preferred because it eliminates the need for girdling, improves the condition of the area for use of mechanized mowers, and extends the length of time the stumps will be flooded. The peripheral portion

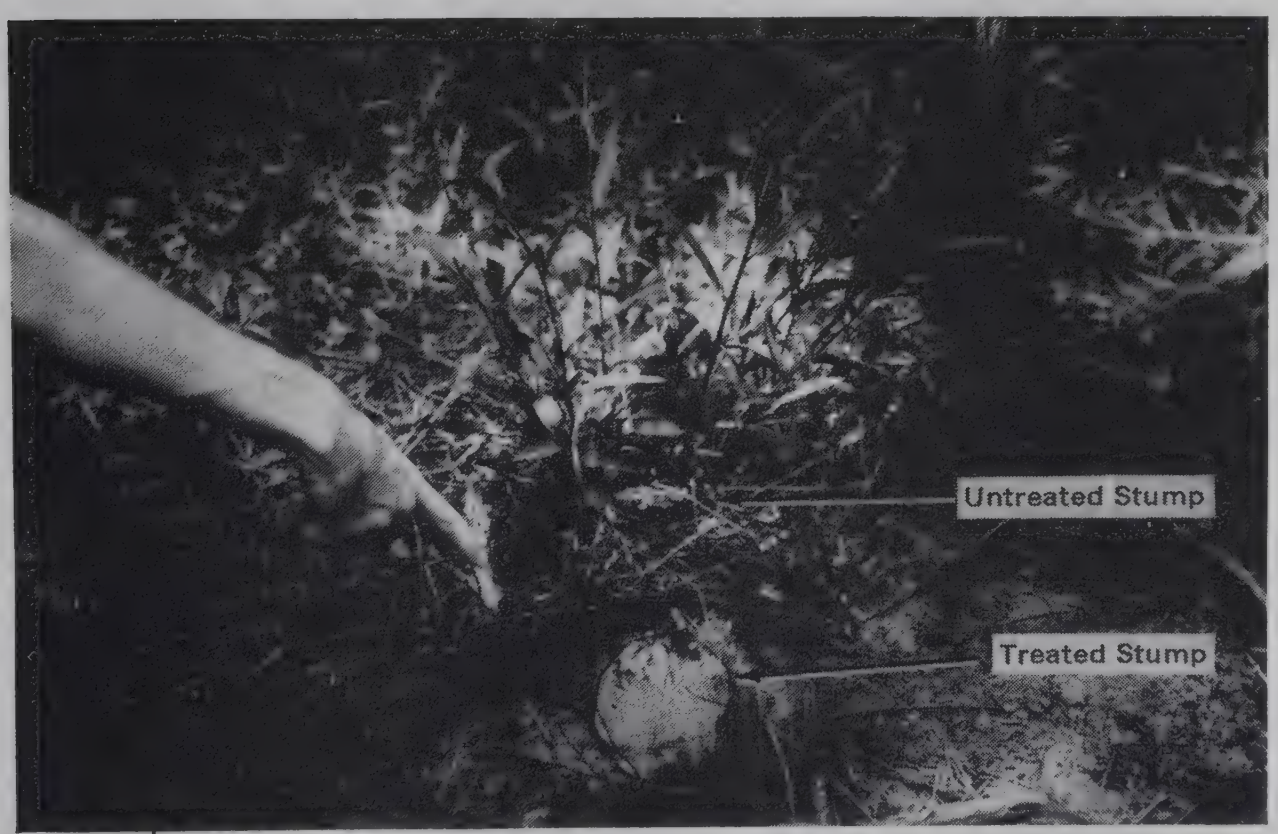


FIGURE 71.—Comparison of a willow stump treated with oil with an untreated stump (sprouting in background).

of large, multiple stumps which are difficult to flush cut perfectly should be beveled off to the ground with an axe before starting to saw.

Low-stumping has been accomplished on timbering operations by use of various mechanical saws with varying degrees of success. Figure 70 shows in action a motor-driven chain saw which is suitable for low-stumping operations. With a saw of this type, it is possible to flush-cut about 400 stumps per day, ranging from 6 to 48 inches in diameter.

The arboricide should be applied to the freshly prepared stumps before they sprout and before other vegetation masks their location.

It should be applied liberally (average rate of 1 pint per stump for stumps with diameters of 3 to 10 inches) to insure complete coverage. A conventional knapsack sprayer used for larvicidal work is suitable for applying the arboricide. Arboricidal materials which have been found suitable for poisoning stumps are kerosene, fuel oil, diesel oil 33° Baumé, and 8 percent aqueous solution of sodium chlorate, and other chemicals commonly used as herbicides. Although sodium arsenite will give excellent results, even in a 1-percent solution, it creates such a hazard to man and livestock that less toxic materials are favored for routine use. Kerosene-black oil (9 parts kerosene, 1 part black oil) has been found to be effective whether applied in the winter, spring, summer, or fall.

Figure 71 shows the effect of treating a stump with 1 pint of kerosene as compared with a stump which was not treated with an arboricide.

The recent development of 2,4-d and other hormone types of herbicides offers new possibilities in the control of coppice. Preliminary tests indicate that year-old coppice of willow may be controlled by spraying the leafy shoots at rates of 1 to 2 pounds of 2,4-d per acre. The development of an effective coppicide to be applied either by airplane or by ground or boat equipment at low rates of application is urgently needed to eliminate costly hand rebrushing operations.

Unit costs of marginal growth removal

The cost of marginal growth removal varies considerably with the size, type, and condition of the areas. Some areas may be conditioned with mowing machines, while others must be worked by hand methods. The cost per acre of machine mowing is considerably less than that of the hand operation as indicated in table 10.

TABLE 10.—*Cost*[1] *of hand and machine operations*

Method	Team- or man-days per acre	Costs per acre		
		Minimum	Average	Maximum
Hand cutting	2 –6	$10.00	$20.00	$30.00
Team mowing	0.20–0.33	3.00	3.75	4.50
Machine mowing	0.10–0.125	2.00	2.50	3.00
Team raking	0.06–0.10	.60	.80	1.00

[1] Costs include cutting, piling, and burning:
Labor @ $0.625 per hour.
Team mower and driver @ $1.25 per hour.
Tractor mower and driver @ $1.60 per hour.

Area burning is one of the least expensive methods of marginal growth removal. As the same amount of labor and equipment is necessary for firing and control purposes per unit length of shore line, the unit acreage costs will decrease as the width of the area to be conditioned increases. Costs including preparation of the firebreak, firing, and precautionary measures are presented in table 11.

TABLE 11.—*Cost*[1] *of area burning operations*

Cost per mile	Method of Preparing Firebreak		
	Hand cut	Machine mowed	Disk plowed
Preparation	$20.00	$ 3.15	$10.00
Firing	1.50	1.50	1.50
Precaution	9.35	9.35	5.00
Total cost per mile	30.85	14.00	16.50

AVERAGE ESTIMATED COST PER ACRE

Cost per acre	Hand cut	Machine mowed	Disk plowed
50-foot depth	$5.20	$2.30	$2.70
100-foot depth	2.60	1.15	1.40
200-foot depth	1.30	.60	.70
500-foot depth	.50	.25	.35

[1] Labor @ $0.625 per hour:
Mowing equipment and driver @ $1.425 per hour.
Tractor and disk and driver @ $5 per hour.

Extensive firefighting has not been included in these figures as it is assumed that careful vigilance will be maintained to prevent any significant uncontrolled fires from becoming started.

Arboricidal treatment for the control of willows has been found to be very effective during both the preimpoundage and postimpoundage operations. Unit costs for flush-cutting and the arboricidal treatment of typical stands of black willow are given in table 12.

TABLE 12.—*Costs of flush-cutting and arboricidal treatment of black willows*

Item	Cost
Labor for flush-cutting stumps[1] (4.0 man-days per acre)	$20.00
Application of arboricide (0.4 man-day per acre)	2.00
Arboricide (average—35 gallons per acre)	3.50
Total cost per acre	25.50

[1] Includes piling and burning of brush.

MARGINAL GRAZING

Marginal grazing may be utilized advantageously as a shore-line conditioning measure. Grazing not only reduces the annual cost of marginal growth removal through the maintenance of a carpet type of vegetation at the expense of coppice and rank herbs but provides continuous removal of plants during the mosquito-breeding season. With fairly intensive grazing during the summer and fall, marginal rebrushing costs may be reduced as much as 40 to 80 percent by eliminating most maintenance operations except the removal of scattered coppice sprouts. Grazing not only significantly reduces anopheline breeding areas, but also reduces the cost and increases the effectiveness of larviciding by decreasing the amount of emergent vegetative cover which interferes with the application of larvicides. The conditions under which marginal grazing would be

utilized as a permanent shore-line improvement measure are discussed in chapter IV.

Proper grazing of marginal lands may contribute to a better economy of the region by fostering diversified farm products, greatly increasing the yield from otherwise unproductive lands, and providing pasture in the dewatered fluctuation zones during dry summer and fall periods when adjoining upland pastures are often inadequate.

Marginal pastures may be grazed by cattle, horses, mules, or goats. These animals will control most rank herbs and coppice along lake margins, but for maximum benefits from grazing, the area should be mowed before the initial release of livestock on the area. Goats are particularly effective for grazing brush. Pasture management of lake margins is, in general, similar to that of upland areas. As in the grazing of upland pastures, certain plants are not readily grazed, and will require supplementary control measures. (See "Relation of Plants to Shore-line Maintenance," ch. XIII.)

The most successful use of grazing for mosquito control is dependent upon (1) the concentration of the animals, (2) supplementary fencing, (3) rotation to prevent overgrazing of upland pastures, and (4) the application of larvicides, when necessary, of a type and at a rate that will not endanger the stock.

The concentration of animals necessary for the effective control of growth in dewatered fluctuation zones in main-river reservoirs will vary with the area but, in an average situation, may be estimated at three horses, cows, or mules, or nine sheep or goats per acre. This will result in heavy grazing of the marginal plants. In storage reservoirs, where dewatering often occurs early in the season, the concentration of stock should be reduced to avoid overgrazing.

Fencing in grazing areas should be so arranged that stock can be alternated between upland and lakeside pastures. (See "Permanent Marginal Grazing," ch. IV.) This dual fencing makes possible proper concentration of the stock in the fluctuation zone and lessens

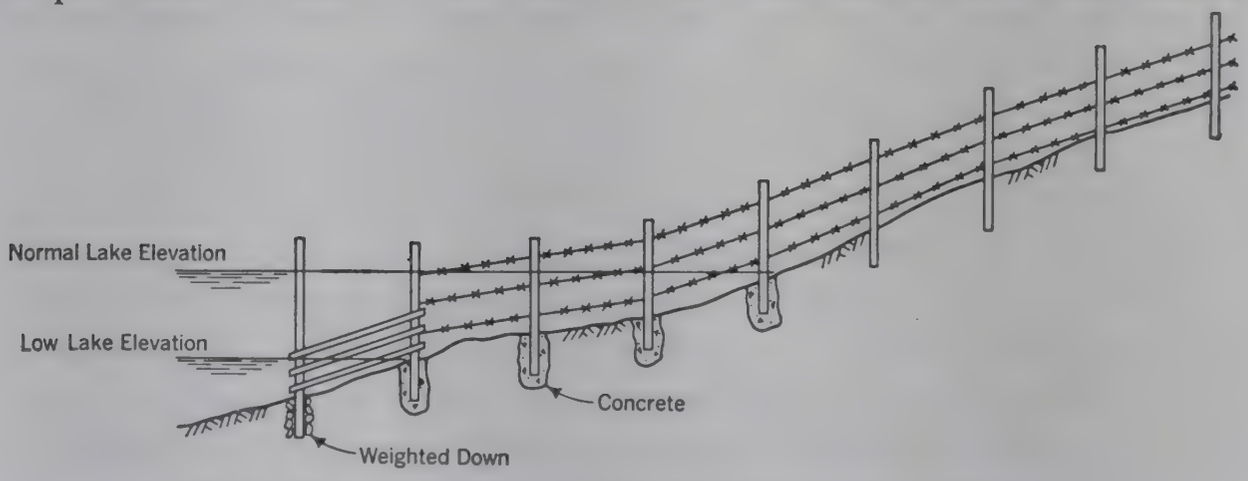


FIGURE 72.—Construction of fences extending into a reservoir.

the danger of overgrazing upland pastures, particularly during periods of drought. Strong, easy-swinging gates should be provided for access to and between pastures. Cattle guards of concrete and iron pipe construction are recommended for access roads entering pasture areas.

Posts of fences extending into the water on reservoirs having wide water level fluctuation should be weighted to prevent their floating during high water periods (fig. 72) . In the interest of navigation, the alinement of the fence should be at right angles to the shore line, and the posts should be tall or flagged to indicate them as obstructions to boat operators during high water.

It is undesirable to have fences isolating small embayments along the shore line. Figure 73 indicates a desired fence arrangement along flat shallow margins. Where areas to be grazed are in low-lying situations or on islands, high ground should be available for the animals to retreat to if a rapid rise in water levels occurs.

DRIFT REMOVAL

Reservoirs that have a flood surcharge require very little drift removal in contrast to those where a flood surcharge is not provided. Drift removal operations should be carried out in the early fall when the lake is low and most of the drift is stranded along the shore line.

Most of the drift and floatage requiring removal is introduced into the reservoir mainly by the larger tributary streams during flood periods. Some of the drift is packed by eddies in the meanders of tributary streams with the remainder being flushed into the main body of the reservoir where, transported by wind and wave action, it usually accumulates in the heads of bights and indentations. In bights and indentations where drift may be lodged and packed tight in relatively deep water, it will be necessary for the men to work in water while tying chains and limbing fallen trees. Normally, in a

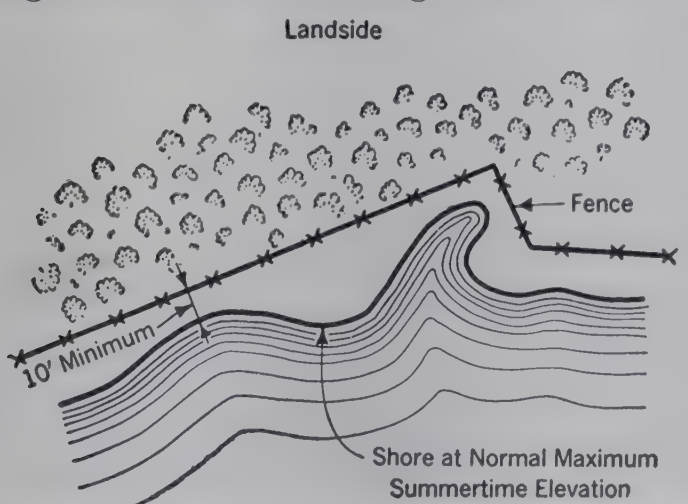


FIGURE 73.—Location of fence with respect to the top summer pool of a reservoir.

FIGURE 74.—Drift piles ready for burning.

reservoir which is low in the fall, drift removal should be undertaken before very cold weather to prevent undue exposure of the workmen.

In instances where small drift is associated with fine flotage and is stranded in windrows the dry material may be burned without further treatment. Drift mats composed of large logs, poles, and branches must be removed by either hand or machine methods, piled, and burned. In hand removal, tree trunks should be cut into convenient blocks which may be lugged with carrying hooks by a four-man team. Hay forks aid in removing and piling small material. Heavy teams may be used to advantage in snaking out the larger logs and in building piles. It may be necessary to use sheaves and blocks to secure good footing for the teams. Drift is usually piled by gathering the large logs at the bottom, building up with smaller logs and poles until the heavy material is sufficiently "wrapped up" for burning as shown in figure 74. Firing is started at the top of the pile by rolling back and replacing the top poles after kindling.

A D–2 caterpillar tractor with a tail winch is an efficient tool for removing logs and trees with a minimum of labor. Where isolated trees have fallen across a tributary arm, a D–2 tractor and winch by a combination of rolling and dragging can remove the entire tree from the reservoir. Fallen trees encountered along steep shore lines where the water is usually deep seldom create favorable anopheline breeding conditions.

The cost of drift removal on impounded water is quite variable, depending on the character of the drift and its location. Drift mats intertwined with all sizes of woody material and packed tightly by wave action must be "picked" apart at a high cost in men and ma-

chine hours. Lacking a better unit, progress of drift removal is usually reported in miles.

TABLE 13.—*Cost*[1] *of drift removal operations*

Method of removal	Man-days per mile	Cost per mile
Hand removal	10–25	$50–$120
Hand and team	8–10	50– 60
Hand and tractor	4– 6	50– 60

[1] Labor @ $0.625 per hour; team and driver @ $10 per day; tractor and driver @ $30 per day.

DITCH MAINTENANCE

All reservoir drainage channels eventually require attention if they are to maintain their maximum efficiency and should be inspected annually. The actual work necessary to keep ditches in shape is moderate if attended to each year, but if the ditches are not properly maintained they will deteriorate rapidly and in a few years will require extensive and costly repair. Marginal drainage for reservoirs is somewhat different from land drainage in that often the entire ditch system is completely submerged, and as a result the ditch channels are better protected against high flow velocities or scouring. The portions of drainage ditches in the upper zone of fluctuation which are dewatered early in the season and submerged for only short periods, therefore, require the most maintenance.

Some common failings of submarginal ditches are (1) sloughing of sandy side slopes, (2) silting of ditch outfalls by streams subject

FIGURE 75.—Silting in ditch without adequate slope.

to flood flows, (3) silting in ditches without adequate flow and gradient (fig. 75), (4) blockage due to drift, and (5) blockage due to aquatic vegetation. Open ditches in sandy situations are difficult to maintain, and without very flat side slopes some sliding will occur at points of alinement change and at outfalls of lateral drainage. Ditches holding water at a constant pool elevation for an extended period will show a marked deterioration at the water line. This is largely due to the inability of maintaining a protective sod which is tolerant to extended flooding. Outfalls of submarginal drainage ditches into tributary streams subject to frequent flood flows often

FIGURE 76.—Lateral ditch clogged with parrotfeather.

require cleaning. Repeated and excessive silting may require abandoning an outfall ditch for a new location which will be more self-cleaning.

Fences, fish traps, or low foot logs should not be permitted in ditches as they catch drift and obstruct the channel. Logs and fine flotage offer no removal problem since they are usually sluiced into the main reservoir when water levels recede. Trees and brush may become lodged in the ditch and require removal. Fallen trees in the channel should be limbed and cut into several sections before removing in order to minimize damage to the side slopes.

FIGURE 77.—Cleaning lateral ditch by hand.

Obstructions due to vegetative growth may sometimes cause failure of the drainage system. For example, ditches draining spring-fed areas often support dense stands of aquatic plants such as parrotfeather. Small mats of this type of plant have been observed to clog a spring-fed drainage ditch (fig. 76) and raise the water level 2 feet

FIGURE 78.—Cleaning ditch with slip and team.

or more, flooding marginal forests and creating an anopheline breeding area. In these types of situations corrective measures should follow procedures as outlined under aquatic growth control.

Tools for drainage maintenance vary from hand shovels to excavating machinery depending upon the type and volume of maintenance required. Long-handled, round-bladed shovels appear to be the most satisfactory hand tool for regrading and sloping small ditches (fig. 77).

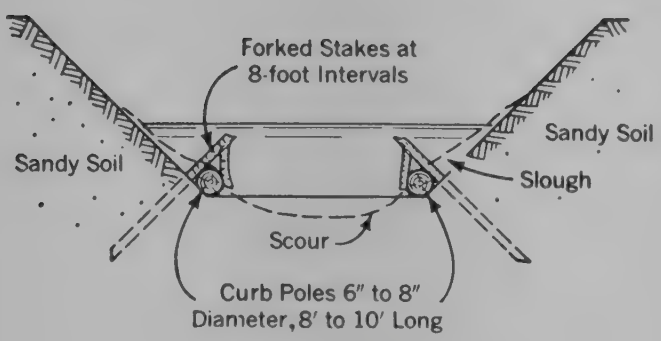
For regrading ditches having a bottom width in excess of 4 feet, teams and slips may be used to advantage (fig. 78). This equipment is particularly suited for cleaning sandy material from ditches. In some instances the excavated material can be used to fill low areas instead of wasting it as spoil banks along the ditch. When maintenance of large or long ditches involves the handling of considerable yardage, excavating machinery should be considered. The size and type of equipment will depend upon various factors such as the location, cross section of ditch, width of berms, volume of excavation, nature of material, and where the spoil material is to be placed. Mobile, lightweight, revolving, dragline excavators mounted on caterpillar treads are especially suitable for cleaning out larger ditches. They will travel over firm ground and with the use of timber mats can be successfully used on reasonable soft or swampy ground. Dragline equipment may be transported to new locations by means of a float-trailer without disassembling. In some situations, particularly in wet materials, an orange-peel bucket may be substituted for the scraper bucket. One operator, and one oiler and grade checker, usually comprise the crew of a small excavating machine.

Drainage maintenance costs will vary, depending upon the frequency of cleaning and the types of equipment used. In general, hand methods are too costly for big ditches and should only be used for minor submarginal ditches and laterals. Drainage maintenance is usually best reported in lineal feet rather than cubic yards. Typical drainage maintenance costs are summarized below.

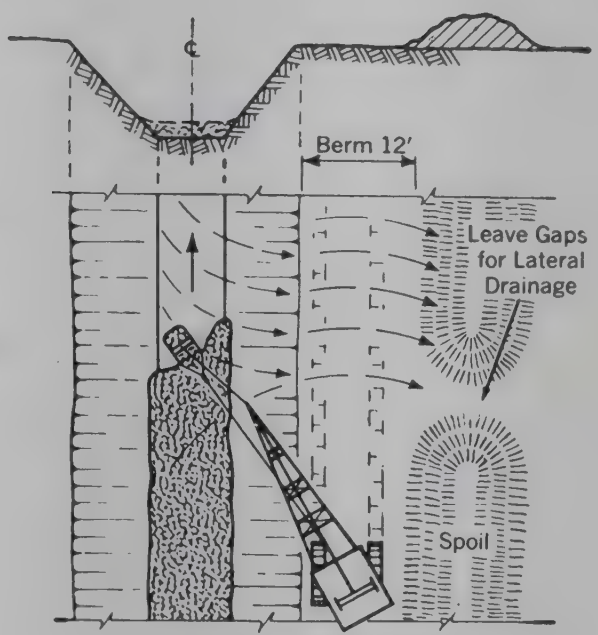
TABLE 14.—*Cost of ditch maintenance operations*

Method	Hours work per 100 feet	Cost per 100 linear feet
Hand cleaning	7–15	$4.50–$10.00
Slip scrapers	5– 8.3	7.50– 12.50
Machine	1– 2	5.00– 10.00

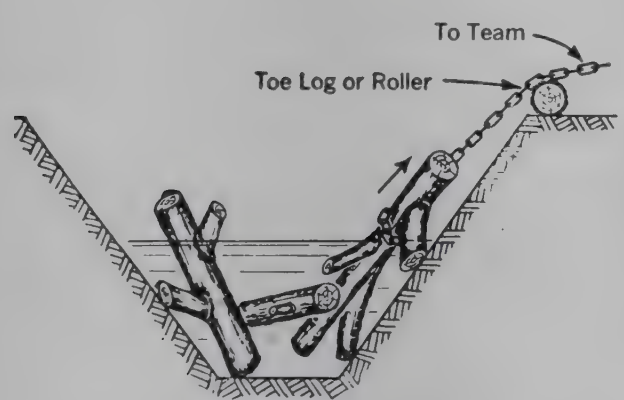
Figure 79 presents several sketches showing details of various reservoir drainage maintenance practices.



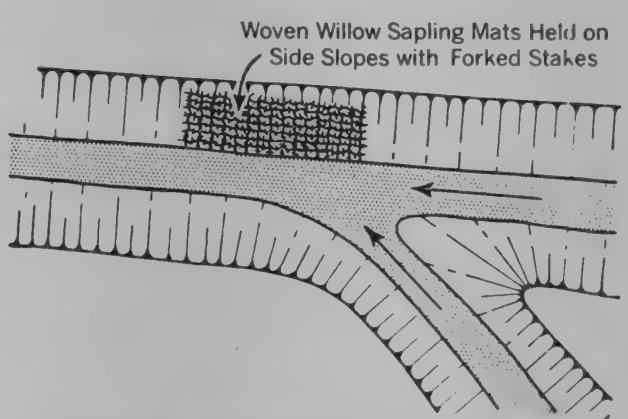
STABILIZATION OF SANDY SLOPES
WITH POLE CURBING



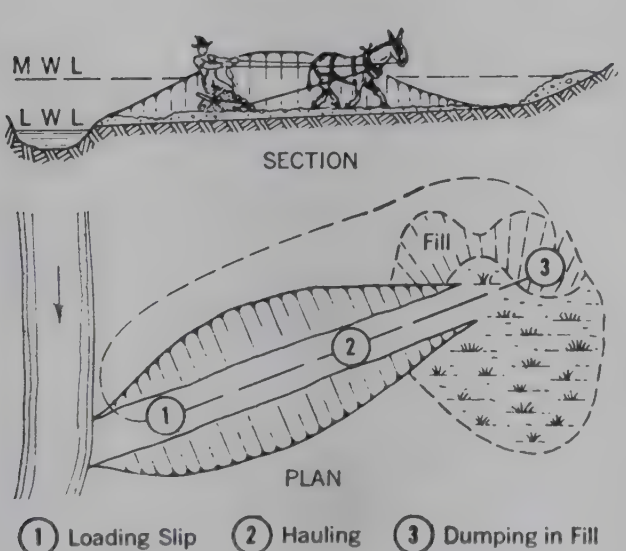
DITCH CLEAN OUT WITH DRAGLINE



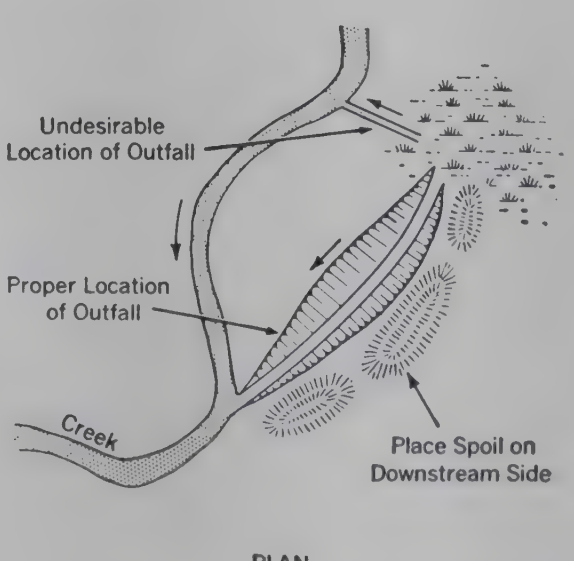
PROTECTION OF SIDE SLOPES
WHILE REMOVING FALLEN TREES



SIDE SLOPE PROTECTION AT LATERAL OUTFALL



COMBINATION DITCH CLEANING
AND FILLING WITH SLIP SCRAPER



DRAINAGE OUTFALL IN FLOOD PLAIN CREEKS

FIGURE 79.—Sketches of various drainage maintenance operations.

AQUATIC GROWTH CONTROL

Aquatic growth control measures are directed primarily against relatively deep-water emergent aquatics. Effective control of any aquatic plant by either mechanical or herbicidal means will be realized best by carrying out a carefully planned and continuous campaign directed at the invader. The guiding principles in the control of aquatic plants are (1) early discovery and proper treatment, and (2) continued vigilance and retreatment.

Figure 80 shows the rapid rate of spread of two typical aquatic species and the effective manner in which eradication or near eradication can be obtained by applying proper control measures during the early stages of colonization.

Fundamental to all aquatic plant control operations is a thorough knowledge of the distribution, habitat requirements, rate of growth, methods of reproduction, sprouting in relation to water levels, and means of migration of each species concerned. With this information, mechanical or herbicidal control measures for the particular species may be developed and an over-all control program planned.

Mechanical control

Mechanical measures are limited to those herbs whose cut portions do not sprout and produce new plants vegetatively.

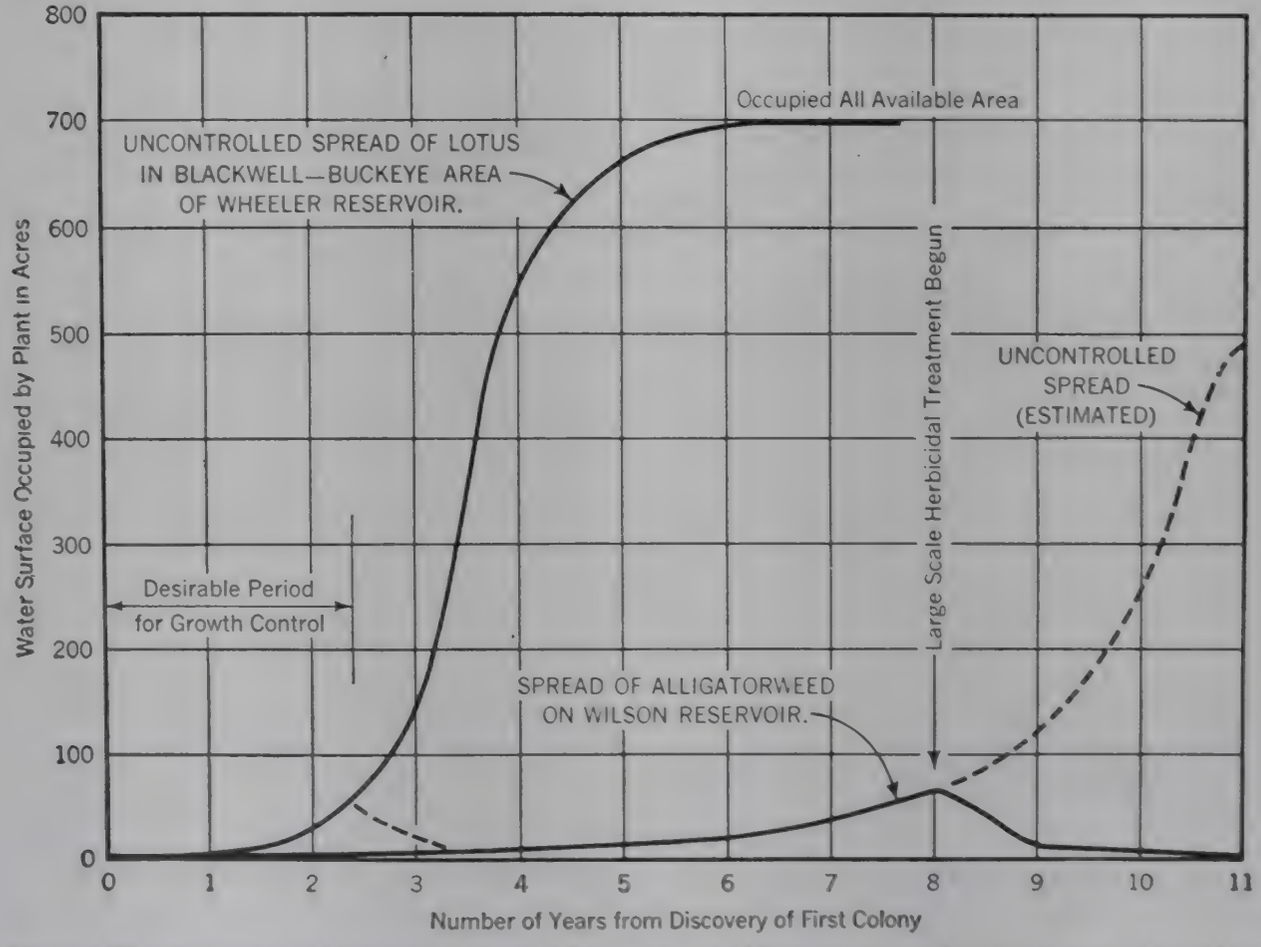


FIGURE 80.—General colonization rates of lotus and alligatorweed showing most desirable period for initiating control measures.

Cutting—Certain aquatic species which colonize shallow water areas and are not spread by fragmentation lend themselves readily to cutting and flooding techniques. Species in this category are mainly monocots and include rush, giant cutgrass, woolgrass, and cattail. These plants may be cut by hand or machine methods, but the time of cutting must be carefully selected during the growing season. A single, relatively short, but continuous period of shallow flooding of the cut stubble has given excellent control in many instances. Cattail may also be controlled without flooding by mowing dewatered plants two to three times in the growing season during periods of low pool levels. Deep-water, floating-leaf aquatics, such as lotus and cow-lily, may be slowly "starved" by repetitive cutting of the leafy or food-producing portions and depleting the reserve food supply in the rootstock. The number of cuttings required to eliminate a colony will vary with the amount of food reserve, age of the plants, depth and turbidity of the water, and the season. For small, newly established colonies, one to two cuttings in relatively turbid water 3 feet or more in depth usually will eliminate the colony. Only the leaf blade need be removed to obtain the desired results, and apparently no advantage is obtained by cutting the petioles lower. Small colonies may be treated by snapping the petioles by hand, by cutting the leaves with sharp grass hooks fastened to a 5-foot hoe or garden rake handle, or by circumscribing the colony with a stout wire fixed to the shore line and pulling the wire by hand or team until the

FIGURE 81.—Underwater weed cutter for cutting floating leaf aquatics.

petioles are severed. Larger colonies can be cut readily and economically with a machine, such as the Hockney underwater weed cutter (fig. 81), at a rate of 3 to 5 acres per day. This unit has duck-foot propelling paddles which "step" clear of aquatic vegetation and afford positive propulsion in very dense stands of aquatic herbs.

Pulling, grubbing, and raking.—Hand pulling and grubbing of certain objectionable aquatics of the erect leafy and erect naked types are practical and efficient methods for eliminating very small colonies of obnoxious plants before they become widespread. These methods are best applied to herbs and woody species which do not sprout from root fragments left in the soil. Even some plants with relatively large root systems may be pulled efficiently if done immediately after draw-down while the soil is very wet. Grubbing with a shovel or hoe may be used to eliminate widely scattered plants too large for convenient hand pulling, but is not practical if a large number of specimens is involved. In either technique, care should be exercised to remove all of the top growth below the "crown" of the plant and to dispose of the plant.

Raking or rolling out on the bank certain floating-mat types of plants, such as alligatorweed, gives, at best, only temporary relief since roots of these plants sprout readily in water up to 2 feet in depth. Furthermore, the plant is brittle and breaks up into numerous floating reproductive fragments which may result in further dissemination of the species. It appears that raking plants of this type should not be generally employed. However, small colonies of giant smartweed, a floating-mat plant, in water 6 feet or more in depth have been permanently eliminated by removing plants with rakes.

Conveyors, crushers, and rotary saws.—Special conveyors, crushers, and rotary saws have been developed by the United States Corps of Engineers for the control of water hyacinth. Small conveyors, mounted on pontoons, have been used for many years, along narrow streams, to elevate the plants and cast them onto the stream banks where most of them die. Because of the cost of this operation, special crushers have been devised which consist of a self-propelled barge with an endless conveyor which elevates the plants to a crusher of corrugated rollers. The crushed plant parts are discharged into the water where they sink in a relatively few days. The most recent development is the rotary saw destroyer which consists of two or more banks of rapidly rotating circular saws mounted on a barge. These rotary saws have relatively dull, forward-directed teeth 1 to 2 inches apart. They saw through the floating mat of water hyacinth with sufficient bruising to prevent regeneration of the dissected parts of the plant. This unit has the manifest advantage of eliminating lifting the very heavy plant material out of the water.

Herbicidal treatment

A number of herbicides are available and may be used for the control of certain aquatic plants which are not managed readily by water levels. The ideal chemical for eliminating undesirable plants in reservoirs appears to be one which (1) kills all portions of the plant, (2) is nontoxic to man and animals, (3) is relatively cheap, (4) can be easily applied, (5) requires no special plant preparation, such as girdling or cutting to make it fully effective, and (6) can be applied effectively to plants in water.

Herbicides may be classified into two major groups; namely, (1) nonhormone type, and (2) hormone type (table 15). Of these, the hormone type of herbicide fulfills most, and sometimes all, of the above requirements of an ideal substance for the control of aquatic plants. It appears that hormone-type sprays may make practicable the effective control of extensive stands of aquatic plants and may in a large measure even supplant conventional herbicides in the near future.

TABLE 15.—*Herbicidal and arboricidal materials*

CONVENTIONAL HERBICIDES

Acid sodium arsenite[1]	Diesel oils
Ammonium sulphamate	Kerosene
Calcium arsenate	Sodium arsenite
U.S.D.A. weed killer[2]	Sodium chlorate

Formagen	*Method of Dispersal*
2,4-d (2,4-dichlorophenoxyacetic acid)	Dusts (or water suspension when combined with a wetting agent.
Salts of 2,4-d	Water solutions.
Esters of 2,4-d	Oil solutions or emulsions.

2,4,5-trichlorophenoxyacetic acid and 4-chloro-2-methyl-phenoxyacetic acid and certain of their derivatives also produce a high degree of physiological activity in plants.

[1] Use 1 part stock solution; 100 parts of water; 5 parts of H_2SO_4. (Stock solution consists of 4 parts of As_2O_3; 1 part of NaOH; 3 parts of water by weight.)

[2] Stock solution: Bogle oil, 3 parts; fuel oil, 55 parts; sodium arsenite, 1 part; and sodium hydroxide, 1 part. (Dilute stock solution with 10 parts of water.)

Regardless of the type of material selected, small-scale field experiments should be carried out on the particular objectionable species under local conditions of water levels, soil, and climate. These field experiments should precede the routine use of the herbicides. The effectiveness of the material should be judged by the degree of resprouting, not merely by the death of aerial portions. Results obtained on small field plots should indicate the material of choice, the form (whether dust or liquid), the time of application, and the period of dewatering required.

In general, herbicides are more effective on broadleaf herbs which have exposed apical growing points than on grass-like plants with

protected growing points. Also, annual herbs are more readily controlled by herbicides than perennial herbs, as the latter have specialized subterranean storage organs which must be killed in order to obtain effective control. Practically all important undesirable aquatics in reservoirs are perennials and, therefore, require the use of herbicides which will bring about the destruction of the subterranean portions of the plant.

Nonhormone herbicides.—The nonhormone, or conventional type of herbicide, is often ineffective on aquatic plants because these plants grow in water which dilutes the herbicidal material, protects the plant, or prevents the plant from having a sufficient root moisture deficit to transport enough of the material internally to effect complete kill. However, these herbicides may be effective if applied during periods of low water levels or for the destruction of above water portions of floating leaf plants where only the removal of the leaf blades is necessary to achieve control.

Sodium arsenite is one of the least expensive and most effective of contact herbicides. It is effective when applied as an aqueous solution, as an oil emulsion, or as a dust, and in coarse soils it may kill the roots as well as the tops of dewatered plants. Of the conventional herbicides, sodium arsenite appears to be one of the most toxic to emergent aquatic plants, but because of its danger to man and livestock, its general use on impounded waters is not advocated. Like most all other nonhormone type of sprays when applied to plants standing in water, it usually kills only the tops down to or slightly below the water line.

Petroleum oils have proved to be very effective for the control of floating-mat plants such as alligatorweed. The oils are not as quick acting as sodium arsenite, but reach and usually kill the deep perennial roots of obnoxious plants such as alligatorweed if applied when the plants are dewatered. Due to the high rates of application of oil required (500 to 800 gallons of kerosene per acre for a plant such as alligatorweed, it is desirable to limit the use of this contact herbicide to relatively small colonies shortly after the initial introduction of the plant into the reservoirs (fig. 82). Recent developments, however, indicate that the much more economical hormone type of spray will yield equal effectiveness and replace the more costly oil sprays. The effectiveness of nonhormone herbicides for controlling a floating-mat plant such as alligatorweed is illustrated in figure 83.

Hormone herbicides.—The high activity of the plant hormone type of herbicide, such as 2,4-dichlorophenoxyacetic acid, or its water-soluble salts, indicates that the control of certain obnoxious

aquatic plants over extensive areas may be not only economically feasible but will yield results heretofore unobtainable by other measures. These so-called plant hormones or formagens give effective control of certain woody and herbaceous plants in reservoirs

FIGURE 82.—Treatment of a small colony of alligatorweed with kerosene. (Note the other marked colonies.)

FIGURE 83.—Small plot of alligatorweed treated with a herbicide. (Note untreated floating mats of alligatorweed in background.)

when applied at rates as low as 1 pound of active material per acre. They kill the plants slowly by derangement of the normal physiological relationships.

The chief advantages of the hormone type of herbicides over the conventional type are (1) kill obtainable with exceedingly low rates of application; (2) treatment of aerial portions of plant results in death of underwater portions, at least for some species; (3) rapid transportation of material into the plant without special preparation of the plant; (4) reflooding of plants treated when dewatered apparently does not decrease effectiveness; (5) practically nontoxic to man and animals; and (6) may be applied as an aqueous or oil spray, as a dust, or in some instances as an aerosol.

Aqueous sprays of formagens, such as 2,4-d acid, may be prepared by using a material such as water soluble carbowax (a polyethylene glycol) as a carrier and spreader. The hormone type of substance is first dissolved in the melted wax and by adding this solution to water, aqueous sprays of relatively high concentrations (up to 1,500 p.p.m. with various formagens) can be prepared. A number of commercial preparations of formagens are available for making aqueous sprays which are usually prepared by adding approximately 1 pound to 100 gallons of water. Aqueous sprays made from water soluble salts of 2,4-d can be prepared without the use of a special solvent or carrier. In applying aqueous sprays to waxy-leaf aquatic plants, fine mist or aerosol sprays appear to adhere better to these surfaces than coarse sprays and, therefore, give more effective control.

Formagenic oil sprays such as TCP acid, may be prepared by dissolving the active material in cyclohexanone (about 4 pounds per gallon) and mixing small quantities of this stock with appropriate quantities of kerosene or other oils, depending upon the concentration desired. Certain polymethyl naphthalenes, such as Velsicol, have also been found to be satisfactory carriers for formagens. Oil sprays containing 1 percent of active material have been found to be effective on some emergent aquatics when applied at a rate of approximately 12 gallons of spray per acre or approximately 1 pound of formagen per acre. A complete break-up of the solution into a multitude of fine droplets appears essential to obtain adequate coverage of the plants. Atomizing spray nozzles rated at 12 gallons per hour at 40 pounds per square inch pressure have given satisfactory results in the treatment of small plots. The pressure may be developed by a by-pass pumping unit or by hand- or machine-operated air pressure pumps such as are described in chapter VII. Esters of 2,4-d are quite soluble in oils and a number of commercial oil preparations of high concentration are available containing up to 40 percent of active ingredients.

Oil sprays containing formagens appear to have certain advantages over aqueous sprays in treating waxy-leaf aquatic plants in water. These apparent advantages are: (1) the oil functions as a sticker, (2) it functions as a penetrant to get the material into the plants, and (3) the oil droplets which miss the plant will float upon the water surface and many droplets may ultimately come in contact with the plant. Thus, the use of oils as a carrier would prevent the loss of valuable material through dilution. Nevertheless, it should be pointed out that aqueous sprays are effective on some waxy-leaf plants.

Airplane methods for the application of hormone herbicides will undoubtedly be developed in the future, this would make it practicable to treat large acreages of aquatics, such as water hyacinth, lotus, and water chestnut with either dusts, sprays, or aerosols. Recent observations indicate that lotus can be controlled effectively and efficiently by 2,4-d herbicides, applied by ground or airplane equipment at rates of 1 to 3 pounds per acre.

MINOR SHORE-LINE TOPOGRAPHY ALTERATION

Along with fall shore-line maintenance activities, there is usually a period of several weeks of good weather when certain minor shore-line improvements can be made that will reduce the mosquito-breeding potential of an area and facilitate subsequent shore-line maintenance. These measures, sometimes called "minor shore-line topography alteration," usually involve minor cut and fill operations such as illustrated in figure 84. As stated above, the objective of these measures is not necessarily aimed at complete elimination of the problem, but at decreasing the breeding potential of the area. For example, the elimination of "hog-back" islands at the mouth of a small embayment may greatly reduce the mosquito production in the backwater area by exposing it to wave action. Similarly, grading a shore line having numerous hummocks and swags will reduce the anopheline breeding area. In other instances, grading can be combined with stump removal if the stumps are fairly well decayed. An incidental benefit of shore-line grading is the removal of coppice and other objectionable plants. Usually, these measures are limited to small areas of 1 acre or less where the cost of the work can be balanced against savings in maintenance operations. No extensive predesigned plan of improvement is necessary. The work to be done and techniques to be used can generally be worked out in the field.

Conventional cutting and filling within the problem zone of the reservoir affords the most typical and effective minor shore-line alteration.

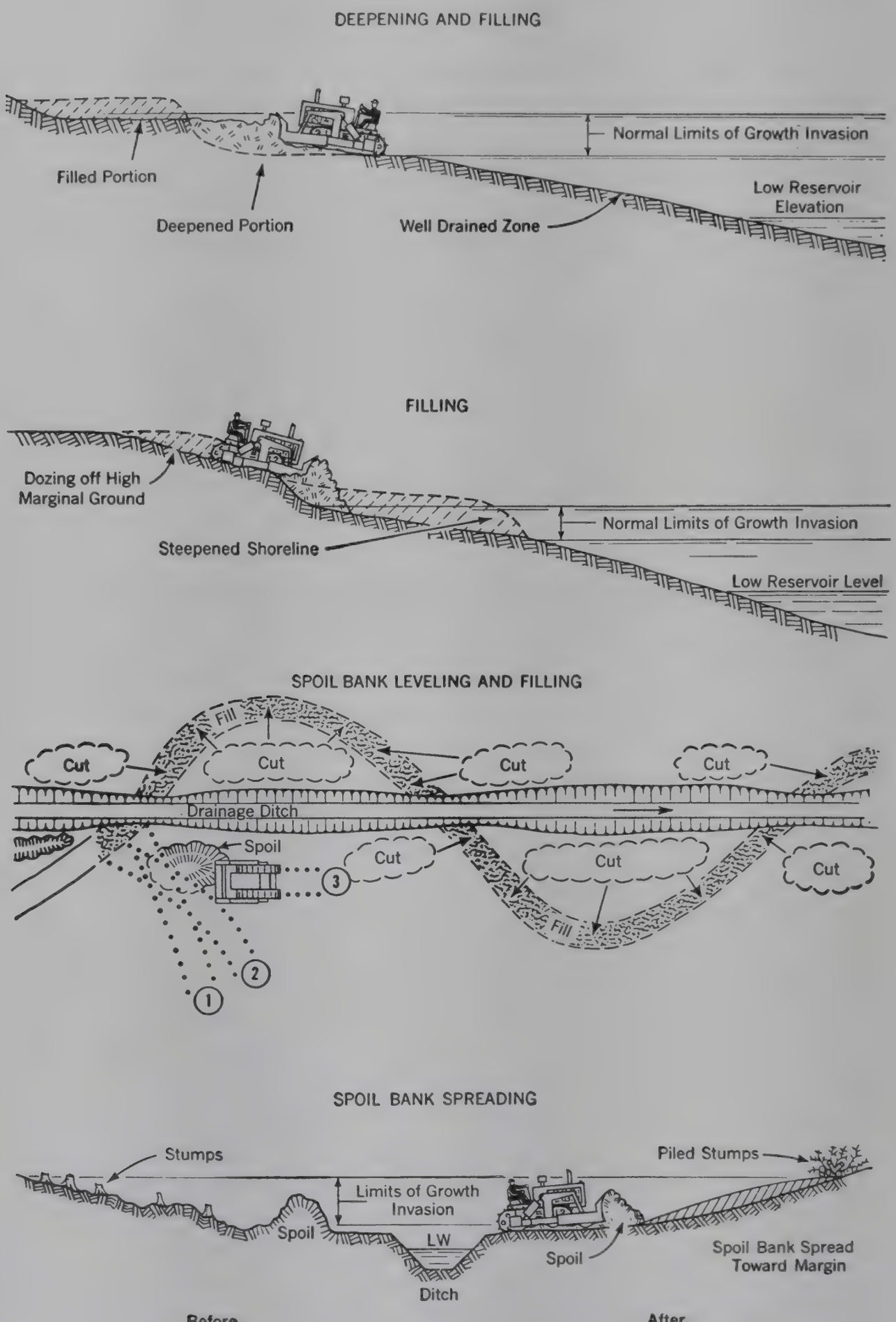


FIGURE 84.—Typical minor shore-line alterations.

Minor cutting and filling operations do not differ in principle from similar measures discussed under filling and deepening in chapter IV. In the actual field execution of minor work, however, yardage estimates and balance lines are of very little practical value. The small size of the areas requires that only the limits of the cut and fill areas be accurately staked. The equipment operator and spotter then may visually prepare the steeper shore line between these staked lines.

Equipment used for these measures may be either hand tools or mechanized units. Hand tools can be used for filling very small depressions, but conventional earth-moving equipment such as tractor scrapers and bulldozers are usually required for the larger areas. Where equipment pools are available, these items may be obtained for short periods as needed. In some instances it may be possible to rent equipment from a local contractor or from the State highway maintenance department. The character of minor shore-line topography alterations does not lend itself to performance by contract since the cost of engineering plans and inspection required would in some instances exceed the cost of the actual construction. The cost of minor shore-line improvement can usually be justified when the annual savings in larviciding and shore-line maintenance will pay the interest and amortize the estimated cost of improvement in 4 or 5 years. The cost of minor shore-line topography alteration will vary considerably, depending upon the degree of improvement, grouping of projects, and type of equipment available. For machine operations, the cost may vary from $30 to $150 per acre of problem area improved.

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VII. LARVICIDING

GENERAL

Larviciding is a mosquito control measure directed at the aquatic stages through the application of toxic materials to the breeding area. The materials used may be conveniently divided into two classes: (1) stomach poisons, which must be ingested by the larvae; and (2) contact poisons, which penetrate the body wall or the respiratory system. Of the available larvicidal materials, paris green, calcium arsenite, and cuprous arsenite are stomach poisons, while oils and the pyrethrins are contact poisons. Such materials as DDT and benzene hexachlorocyclohexane act both as contact and stomach poisons.

Larviciding was initiated in 1892 by Howard's recommendation that kerosene be used to control mosquito larvae. The second important discovery in this field was that of Barber and Hayne, who in 1921 first applied paris green dust for control of anopheline larvae. Since that time no new larvicides of importance were developed until the impetus of war research brought about the development of DDT. This and other similar materials promise to reduce greatly the cost and increase the effectiveness of larvicidal measures.

As discussed in chapter II, the extent of larviciding on impounded waters can be reduced through proper reservoir preparation, water level management, and shore-line maintenance. However, there are a number of circumstances under which the use of larvicides is required. Larviciding may be needed during the early part of the breeding season while a constant level pool is being maintained to retard the marginal invasion of plants. Interruptions in normal water level schedules due to flood or low stream flows may result in emergency situations where the use of larvicides is necessary for the control of mosquitoes. Larviciding may also be required for mosquito control on constant level pools such as navigational and recreational impoundments. Flood control or other reservoirs which have water level schedules unfavorable for mosquito control may require larviciding as a control measure. Mosquito control on reservoirs having extensive areas of floating aquatic plants may also require the use of larvicides. Finally, larviciding may be used as a temporary measure during construction of permanent mosquito control works.

Regardless of the situation which may call for the use of larvicides, the operation must be carefully supervised to insure that it is confined to actual breeding areas and achieves the desired results.

SELECTION OF MATERIAL AND METHOD OF APPLICATION

The selection of a larvicidal material and its method of application will depend on several factors such as cost, effectiveness, scale of operation, type of area to be treated, and toxicity to wildlife. The choice of such materials is further limited to those which can be most efficiently applied by the facilities which can be provided. Where the preceding requirements can be met, it is sound practice to utilize the most toxic larvicide available in order to minimize labor costs and to lessen the deficiencies of faulty application. The relative costs of various materials used for anopheline larvicides is indicated in table 16 which may be of value in the tentative selection of larvicides. A reasonable degree of effectiveness should be obtained with the application rates indicated. Costs will vary widely with the price of materials, labor, machine rentals, character of the mosquito-breeding area, etc. The costs given in the tables are for the purpose of providing some idea of relative costs between the various larvicides and methods of application. In the preparation of estimates, current local costs should be used. The material selected should also be one which can be uniformly and efficiently applied over the breeding areas being treated. Proper application is very important as even the most effective material will fail if improperly applied. The selection of a method for application will depend on the extent and character of the area to be treated.

Larvicides may be applied by hand-powered equipment carried by the operator, or by boat or truck units. These methods are best adapted to the treatment of small ponds, drainage ditches, and certain areas of large reservoirs such as heads of hollows, narrow strips of shore lines and ditches. Such methods do not require a high initial outlay for equipment or a high degree of operational skill and are therefore particularly suitable for operations of a limited scope.

The disadvantages of hand application are the high cost of labor and supervision, the difficulties involved in treating many typical breeding areas, and the lack of uniform distribution sometimes resulting in a waste of expensive larvicidal materials. In any hand operation every effort should be made to use the most effective materials which will increase the range of operation and insure more adequate kill. Power methods are cheaper than hand methods, but both boat and truck equipment are limited in reaching many breeding areas on impounded water and have relatively high maintenance costs. An inherent disadvantage in any surface operation lies in the fact that the rate of deposition of spray, aerosol, or dust particles, traveling downward, decreases geometrically with the distance from

TABLE 16[1].—*Relative costs of various anopheline larvicides*

Material	Methods of application	Average rate of application per acre for effective (90 percent) larval control	Unit cost	Approximate material cost per acre
Fuel oil or kerosene	Hand spraying; power spraying	30 gallons	.10 cents per gallon	$3.00
Methylated naphthalenes	....do....	5 gallons	47 cents per gallon	2.35
Pyrethrum emulsion	....do....	5.5 gallons (Dilute with 10 parts water for application)	42 cents per gallon (mixing 5 cents)	2.32 + .28 2.60
1 percent DDT in fuel oil	....do....	1 gallon (0.05-0.1 pound DDT)	14 cents per gallon (mixing 2 cents)	.14 + .02 .16
20 percent DDT methylated naphthalene	Airplane spraying Airplane aerosoling	¼-quart (0.05-0.1 pound DDT) (0.1 pound DDT)	$1.54 per gallon (mixing 2 cents)	.10
DDT emulsion	Hand spraying; power spraying	1 gallon of 1 percent emulsion (0.05-0.1 pound DDT)	14 cents per gallon (mixing 4 cents)	.14 + .04 .18
20 percent paris green dust	Power dusting; airplane dusting	10 pounds (2 pounds paris green)	4.5 cents per pound (mixing 1 cent)	.45 + .10 .55
10 percent paris green dust	Hand dusting	10 pounds (1 pound paris green)	2.5 cents per pound (mixing 1 cent)	.25 + .10 .35
Calcium arsenite (undiluted)	Hand dusting; power dusting; airplane dusting	7 pounds	5 cents per pound	.35
5 percent DDT dust	....do....	4 pounds (0.2 pound DDT)	3 cents per pound (mixing 1 cent)	.12 + .04 $ .16

[1] Formulations and specifications of materials mentioned in this chapter are given in appendix C.

the point of release. The rate of decrease is influenced by density of vegetation, wind velocity, and particle size. In actual practice, this results in vast overtreatment of the area adjacent to the origin of the dispersal equipment in order to obtain the required rate of deposition at the desired distance downwind. This factor decisively limits the depth of treatment which can be obtained in any operation. Variable breezes frequently make it difficult to get to windward of the area to be treated, and frequently subject the operator to the cloud of dust or spray. This difficulty is especially troublesome in the case of power units on truck or boat unless special roadways or waterways exist on all sides of the area to be treated. A partial solution to these problems has been attained in the development of a power unit which projects a stream of water-oil mixture up to 100 feet with sufficient force to penetrate heavy vegetation.

Airplane application of larvicides is best suited to the treatment

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of shallow areas of considerable size and long, wide strips of shore line. It is almost the only practicable method for treating heavily timbered areas in emergency situations. The airplane has few limitations in reaching the area to be treated, the treatment rate is very rapid (18 to 40 acres per minute), and the distribution of the larvicide is relatively uniform. The feasibility of using airplanes for applying larvicides has been greatly increased by the introduction of materials, such as DDT, which when used in concentrated form have greatly increased the pay load. In small-scale operations, the overhead costs of equipment and maintenance may make the use of the airplane impractical; however, contract service for a fixed cost per acre can often be obtained.

With careful planning to avoid nonessential flying and to keep layout facilities to a minimum, airplane larviciding should be the most economical method for applying larvicides on medium- to large-sized reservoirs.

INITIATION AND FREQUENCY OF LARVICIDING

The initiation and frequency of larvicidal operations are dependent upon the abundance of anophelines, which is dependent upon climatological factors and upon seasonal water level management. The areas to be treated will be defined by the findings of larval and adult mosquito inspections. When mosquito production is significant, treatment usually will be required at weekly intervals regardless of material used or method of application. After larvicides have been applied they are subject to wind and wave action, stranding, evaporation, precipitation, and decomposition, and are, therefore, not effective for long periods. Overtreatment sufficient to produce significant residual effects is not practicable under conditions found on impounded water.

TYPES OF LARVICIDAL MATERIALS

Paris green

Paris green is the name commonly used for copper aceto-arsenite. The commercial product is a vivid green granular material having a specific gravity of 3.21. Commercial paris green weighs from 60 to 100 pounds per cubic foot depending upon the particle size and degree of packing. Specifications for larvicidal paris green are given in appendix C.

Paris green is toxic to mosquito larvae as a stomach poison, and is effective as an anopheline larvicide because of the surface feeding habits of *Anopheles* larvae. Particles of paris green on the water surface are drawn into the esophagus by the current created by the

rapidly moving larval mouth brushes and are swallowed. The paris green is soluble in the acid contents of the larval gut and poisons the insect. A lethal dose to fourth instar *A. quadrimaculatus* larvae is contained in a particle of paris green about 50 microns in diameter weighing approximately 0.0002 mg. The maximum size paris green particles which anopheline larvae can ingest determines the maximum particle size composition of the larvicide. The maximum diameter of particles which can be swallowed by *A. quadrimaculatus* larvae are approximately as follows: 1st instar—30 microns; 2nd instar—50 microns; 3rd instar—70 microns; and 4th instar—100 microns.

The use of a diluent is advisable in applying paris green as a dust in order to secure more uniform application at the desired rate of treatment. Diluents which have been used are hydrated lime, soapstone (talc), road dust, and other similar materials. Where large amounts of diluent are required, the use of a standardized material is advisable. Since soapstone is readily obtainable in large quantities at a moderate price and has the desired physical properties, it is recommended as the most practical diluent. It weighs 40 to 50 pounds per cubic foot when loosely packed. Specifications for this diluent are given in appendix C.

For hand or boat dusting operations, a 5 to 15-percent (by weight) mixture of paris green and soapstone is recommended to reduce the bulk to be handled. Experimental data have also shown that dilution of paris green dust below 5 percent significantly reduces the effectiveness of the larvicide. In the application of paris green by airplane a concentrated dust should be used to increase the effective pay load, but a light colored diluent should be added to provide a marker and to increase the uniformity of distribution. A dust containing 20 to 25 percent paris green is recommended for airplane dusting, although a 50-percent dust of paris green has also been used. A 20-percent paris green dust mixed with soapstone weighs from 43 to 65 pounds per cubic foot depending on the weights of the materials and the packing.

DDT

DDT is a synthetic organic compound having the formula $(ClC_6H_4)_2CHCCl_3$. The commercial product is a whitish, waxy, granular powder consisting of 60 to 80 percent of the active para-para isomer, 5 to 20 per cent of the ortho-para isomer which is relatively nontoxic, and lesser amounts of other organic and inorganic impurities. The specific gravity of DDT is 1.5 and the density of loosely packed technical grade DDT is approximately 50 pounds per cubic foot. Specifications for DDT are given in appendix C.

The specific action of DDT on insects has not been clarified at present, but it acts primarily as a nerve poison destroying coordination of movements which is followed by hyper-activity, paralysis, and death. Anopheline larvae when poisoned by DDT lose their ability to remain at the water surface and are probably killed by drowning since their gill system is inadequate for continuous underwater respiration. As a dust DDT can act on mosquito larvae either as a contact or a stomach poison, while in an oil solution the principal action is by contact, especially through the spiracles. Although DDT will kill anopheline larvae when applied at very low concentrations (0.05 to 0.1 pounds per acre), it is not very toxic to pupae and does not affect eggs.

Because of its inherently sticky nature, DDT must be highly diluted before it can be dusted properly. If DDT dusts are mixed by ordinary methods, a 5-percent mixture with soapstone is the highest percentage that can be relied upon to dust evenly and not cake. However, powders with higher percentages of DDT and with good dusting qualities can be prepared by special commercial grinding processes. A 1- to 2-percent dust suitable for hand-dusting operations can be prepared by diluting a commercial 10- to 25-percent DDT powder. A 5- to 10-percent dust should be used in airplane application. Mixed DDT dusts vary in weight from 40 to 50 pounds per cubic foot depending on the weight of the soapstone diluent used.

DDT is readily soluble in a number of organic solvents, and the resulting mixtures are highly effective against larvae and adult mosquitoes. The most practical of these solutions together with their important physical properties and DDT solubilities are given in table 17.

TABLE 17.—*DDT solvents suitable for larviciding*

Solvent	Solubility of DDT, grams per 100 ml. at 25° C.	Boiling point range, °F.	Flash point, °F.	Weight, pounds per gallon at 20° C.
Kerosene, commercial	8	296–502	148	6.8
Kerosene, refined[1]	4	349–469	138	6.84
Stoddard's solvent	9	350–410	103	7.16
No. 2 fuel oil	10	340–536	135	6.8
Dimethyl naphthalene	60	456–516	150	8.3
Tetramethyl naphthalene	47	496–674	300	8.55
Xylene	56–62	252–318	90	7.17

[1]A so-called fireproof kerosene is available which will dissolve 9 grams of DDT per 100 ml. of kerosene

For hand and boat larviciding, 1- to 5-percent solutions of DDT in crude kerosene or No. 2 fuel oil are suitable. For application from aircraft where the payload is an important factor more concentrated solutions are desirable although a 5-percent solution in No. 2

fuel oil has given good results. A 20-percent solution of DDT in tetramethyl naphthalene is recommended for airplane application either as a spray or aerosol. This solution is especially desirable because of its high flash point and high DDT concentration. It weighs 9.35 pounds per gallon. In addition, the solvent possesses considerable toxicity to mosquito larvae.

DDT dissolved in xylene and emulsified in water may also be used as a larvicide. This formulation tends to disperse under the water surface and is very toxic to culicine and anopheline larvae but is also more toxic to fish and other aquatic organisms than are formulations which remain on the surface. The formulation rusts equipment very badly and in general is less desirable for anopheline larvae control than DDT-oil solutions. (See appendix C for formulae.) Some emulsion formulations used are: DDT 25 to 30 percent, xylene 68 percent, and 2 to 7 percent emulsifier.

Oils

Petroleum oils are toxic to mosquito eggs, larvae, and pupae if applied at the recommended rates. The chemical composition of oils is important in larviciding because of its relation to toxicity. Physical properties, such as volatility, surface tension, viscosity, and specific gravity, are also of importance in determining the relative larvicidal qualities of various materials.

The toxicity of an oil to larvae is related to its volatility. Volatile oils produce an anesthetic effect when they penetrate into the tracheae of the larvae. Heavy nonvolatile oils act much slower and generally do not have any direct toxic action but suffocate the larvae by mechanical interference with breathing.

In general, for a larvicidal oil to be effective it should kill within 1 to 2 hours after contact of the larvae with the oil. The following table shows the relative toxicities of various commercially available petroleum oils to *A. quadrimaculatus* larvae. It should be noted in table 18 that refined aliphatic oils (Nos. 1 to 4) are the least toxic, and that an oil such as monomethyl naphthalene (No. 5), containing a high percentage of aromatic compounds is much more toxic.

TABLE 18.—*Relative toxicities of various larvicidal oils to* A. quadrimaculatus *larvae—laboratory tests*

Material	Rate of application, gallons per acre	Percent mortality to 4th instar larvae			
		5 minutes	20 minutes	1 hour	24 hours
1. Kerosene, refined	1	0	0	0	10
2. Kerosene, commercial	1	0	10	20	65
3. Fuel oil (Diesel oil)	1	0	15	25	30
4. Stoddard's solvent	1	0	25	50	50
5. Monomethyl naphthalene	1	60	100	100	100

Another factor of importance in the use of oil larvicides is the spreading coefficient of the oil. Those with high positive values have better spreading characteristics. The spreading coefficients of several oils are given below:

Material:	*Spreading coefficient*
Neutral white oil	−15.9
Kerosene, refined	− 4.6
Kerosene, commercial	+ 0.5
Light stove oil	+11.8
Diesel oil	+19.7

The spreading power of petroleum fractions is due to small traces of impurities as is shown by the very poor spreading powers of the highly refined oils as compared to crude oils. Because of their better spreading properties and their greater toxicity, crude (unrefined) distillates are preferred for larvicidal oils.

In actual oiling operations, it has been found that, due to the resistance of natural surface films, even oils of high spreading power frequently do not give coverage unless mechanical dispersion of the oil is used. For example, in knapsack oiling the oil is spread by the churning feet of the operator, and in boat oiling operations a stream of water-oil mixture under high pressure breaks up the surface film and aids in the distribution of the oil. Such methods of application increase the effectiveness of oils having relatively low spreading properties.

Although much has been written concerning desirable specifications for larvicidal oils, in actual practice the user is limited to those materials obtainable in large volumes, at moderate prices, and of uniform composition. The two most popular materials have been fuel oil distillates, such as No. 2 fuel oil and commercial kerosene. These two materials are generally available and appear to be equally toxic to larvae. The fuel oil apparently has slightly better spreading properties. However, attention should be called to the newer aromatic oils now available. These materials are methylated naphthalenes and can be obtained in increasingly high boiling fractions containing, one, two, three, and four methyl groups per molecule. They are much more toxic to larvae than the aliphatic oils and work well in combination with them. However, some of them are heavier than water and so cannot be used in quick breaking emulsions as can the paraffin oils. Commercially available larvicidal oils were given in table 17. The addition of 10-percent black oil to the larvicidal oil to serve as a marker will facilitate the application of the oil. Specifications for kerosene and black oil are given in appendix C.

In the past, kerosene fuel oil larvicides have had wide application on impounded reservoirs, but the rapid development of much more

effective and cheaper larvicides may greatly limit the future use of such oils.

Benzene hexachlorocyclohexane

The technical material, benzene hexachlorocyclohexane, consists of 10 to 12 percent of the active gamma isomer, "gammexane," together with the relatively inactive alpha, beta, and delta isomers. It is a greyish to brown crystalline material with an unpleasant, musty smell. The technical material also can be obtained as a dust containing 2-percent "gammexane", which has given good anopheline control in hand-dusting experiments when applied at rates as low as 0.02 pound "gammexane" per acre. "Gammexane" appears to be approximately as toxic to anopheline larvae as DDT. Further experimentation must be carried out with this material before specific recommendations can be made for its use in larvicidal operations.

Pyrethrum larvicides

The New Jersey pyrethrum larvicide has been used to a limited extent but has in many cases produced erratic results. The active ingredients are two carboxylic acid esters, pyrethrins I and II, obtained as extractives from plants of the genus *Chrysanthemum*. This material is obtainable commercially as a kerosene extract usually containing 2 percent pyrethrins. For use as a mosquito larvicide the recommended formula is:

5 gallons of kerosene containing 2 percent pyrethrins
95 gallons of kerosene
6 pounds of emulsifier
50 gallons of water

The emulsifier should be first mixed with water and then the oil added and the mixture agitated until a stable emulsion is formed. This emulsion is the stock material which is then diluted with 10 parts of water by volume. The concentration of the pyrethrins in the final dilute emulsion is 0.005 percent. The material should be applied at the rate of 50 to 70 gallons per acre of water surface and can best be applied with a knapsack sprayer or boat oiling unit. A difficulty which arises in actual practice with this material is that it sometimes merely paralyzes the larvae which sink but subsequently recover and reappear. This material may be used where the application of oil is unsightly or otherwise undesirable. Tests have shown that the quantity of pyrethrum larvicide required to give satisfactory anopheline kill is 1½ to 2 times that of fuel oil or kerosene. Special mixing equipment is required to prepare the pyrethrum larvicide. This larvicide has been widely used in pest mosquito control in New

Jersey, but has had but limited use in anopheline control on impounded water.

Miscellaneous materials

Phenothiaozine or thiodiphenylamine is an organic compound which is quite toxic to mosquito larvae as a contact poison. The compound is a yellowish, greasy material melting at 180° C., is almost insoluble in water, and is slowly oxidized in air. Its effectiveness as a larvicide has been rather erratic. This material, when applied as a 10-percent dust at a rate of 1 pound per acre, has sometimes given good mosquito control. It is very toxic to fish, however, and hence its use is restricted to ornamental pools and other temporary breeding places, particularly for control of *Aedes aegypti*.

Calcium arsenite has been employed to some extent as a substitute for paris green, being applied at rates of 3 to 7 pounds per acre. It is of uncertain composition and contains from 60 to 78 percent As_2O_3 and from 22 to 34 percent CaO; these extremes correspond to the formulae $Ca(AsO_2)_2$ and $CaOHAsO_2$. Other more basic arsenites are often formed having low As_2O_3 contents, and these are unsatisfactory as larvicides.

Copper arsenite [cupric meta-arsenite $CuO \cdot As_2O_3$ or $Cu(AsO_2)_2$] has been employed experimentally as a paris green substitute. It has the following average composition: CuO, 28 percent; As_2O_3, 68 percent; water soluble As_2O_3, 0.8 percent. Because its arsenical content is higher than that of paris green, it has a slightly higher toxicity in laboratory tests. However, due to its crystalline make-up, it cannot be produced with particle diameters over 5 to 10 microns, and, consequently, a great deal is lost during dusting operations due to wind drift. For this reason, it has given erratic results in airplane dusting. When used, treatment at 1 to 2 pounds per acre is generally employed.

Other materials which have been suggested as larvicides but which have not attained any practical importance in this country are: paraformaldehyde, borax, cuprous cyanide (which is stated to be more toxic than paris green), and cresylic acid (distilling above 225° C.) which is very poisonous to fish, plants, and wildlife.

TOXICITY OF LARVICIDES TO OTHER ORGANISMS

By proper application the commonly used anopheline larvicides will not significantly damage wildlife organisms as only a limited number of surface forms will be affected, and the operation usually embraces only a small portion of the total shore line of the reservoir.

Paris green dust is nearly specific for anopheline larvae, and is not harmful to most other aquatic organisms. The use of petroleum

larvicides results in some toxic effect on aquatic forms, especially when heavy applications are required in aquatic vegetation. Experience to date has indicated that DDT dust is nearly harmless to aquatic organisms. DDT oil solutions applied in the minimum amounts necessary for anopheline larval control may kill a few other surface organisms, but do not appear to be toxic to fish or to limit their food supply unless applied in excessive dosages.

Caution should be exercised in the use of DDT sprays near orchards or apiaries in order to avoid killing bees which are very susceptible to this material.

It should be remembered that nearly all larvicides in sufficient concentration are toxic to warm-blooded animals, and care should be exercised to avoid spilling or improperly storing materials. Livestock is not affected by larvicides when properly applied, but overtreatment or local concentrations of arsenical dusts have resulted in the death of livestock and poultry in a few instances.

AIRPLANE APPLICATION OF LARVICIDES

General

In airplane operation, it is necessary that the larvicide be applied during the 3 or 4 hours of early morning calm at as low an altitude as is necessary for cloud control, usually 20 to 30 feet above the breeding surface (fig. 85). Any appreciable wind movement (over 2 or 3 miles per hour) will seriously interfere with the application, as a considerable portion of the larvicide will drift away from the treatment area. Since the calm period is limited, everything must be done to cut down the nontreatment flying time. This may be best accomplished by careful routing to prevent backtracking and by

FIGURE 85.—Airplane application of paris green larvicide.

the convenient location of loading strips. Any reasonably level and smooth strip of land approximately 300 feet wide by 2,000 feet long with clear approaches can serve as a satisfactory loading strip. (See "Airplane Loading Fields," ch. X.) Trees which obstruct airplane operations along the reservoir margins should be removed as a safety precaution and to improve the efficiency of the operation.

In recent years, emphasis has been placed on training the pilot not only in flying techniques but also in the fundamentals of anopheline mosquito control. Such training is essential for the most effective application of larvicides. After the general areas are set out for treatment on the basis of inspections for larvae, the pilot must assume the responsibility for the detailed pattern of treatment.

The qualities most desired in an airplane for the application of larvicides are:

1. Relatively low cruising speed (90–150 m.p.h.)
2. High rate of climb.
3. High load-carrying ability.
4. Lowest possible landing speed.

These qualities are best met by the two-place biplane aircraft designed in the early 1930's and by a few modern military training planes. The biplane is generally more suitable than the monoplane for larviciding. Its relatively shorter wing span permits steeper low-altitude turns and safer access through narrow flight lanes and requires less hangar space. Most biplanes are ruggedly constructed and due to wing position are notably resistant to serious crack-ups upon accidental collision with such obstructions as telephone wires and treetops.

Among the older commercial models suitable for conversion into larviciding planes are: 450 hp. Stearman 4-DX; 200 hp. Huff-Deland PP; 200 hp. Jones Standard D25; 225 hp. Spartan NS1; 300 hp. Laird LCR 300; and Waco straight wing and Travelair 4000 with engines in similar horsepower ranges. In general, light aircraft, such as the Aeronca, Cub, and Taylorcraft, are impractical for larviciding. These ships have low engine power, low payload, and their structural design makes equipment installation difficult. Several suitable models of military trainers are the 220 hp. Stearman PT-17 and 200 hp. Waco PT-14.

In most instances, it is desirable to increase the engine horsepower of the standard models to provide safer performance during the rather hazardous low-altitude flying. Experience of the Tennessee Valley Authority, which operates six larviciding aircraft, indicates that supercharged engines with exceptionally low weight per horsepower developed, and "constant speed" propellers are desirable

features of a larviciding plane. The "constant speed" propeller has a number of advantages over standard propellers on larvicidal operations:

1. Reduced take-off run, 25 to 30 percent.
2. Increased rate of climb, 15 to 25 percent.
3. Increased cruising speed, 5 to 15 percent.
4. Increased safety.
5. Improved engine performance and maintenance.
6. Ease of operation permits pilot to keep throttle at same setting whether climbing, diving, or flying level.

All larvicidal ships should be equipped with night-flying equipment as it is often desirable to fly to treatment areas before daylight. A small rear-view mirror facilitates observation of the larvicidal cloud while in flight.

Airplane application of larvicidal dusts

Dusting equipment is composed of the dust hopper, venturi, agitators, and dust release valve, as shown schematically in figure 86. The hopper should be tight, sturdy, lightweight in construction, and located near the center of gravity of the aircraft. The dust should flow freely into the discharge venturi; this can be aided by a wind-driven agitation arrangement. The venturi, through increased air velocity, effects adequate dispersal of the dust cloud. The dust release valve and control should be adjustable to various required discharge rates, and open and close tightly with a minimum of manual effort. Detailed instructions for the design of airplane dusting equipment are given in appendix E.

Paris green dust.—The dust most commonly used is composed of 20 percent paris green and 80 percent soapstone, by weight, although where payloads are limited the paris green content may be increased to 50 percent. The 20-percent paris green mixtures have a normal variation from 9 to 13 pounds paris green per cubic foot of mixed dust depending on the density of the paris green used.

Loading the dust into the plane should be carried out rapidly, and preparations made before the airplane arrives. The dust is usually loaded at the dust storage house on a four-wheel baggage cart or pick-up truck and hauled to the plane on the field immediately after it lands. Loading is best accomplished by a two-man team. One man opens the containers and passes them up to the man on the wing walk, who loads the hopper (fig. 87). After the lid is secure on a loaded hopper, the surface of the fuselage in front of the cockpit is carefully brushed off before the motor is started. The valve should be set in accordance with the density of the dust given on the tag

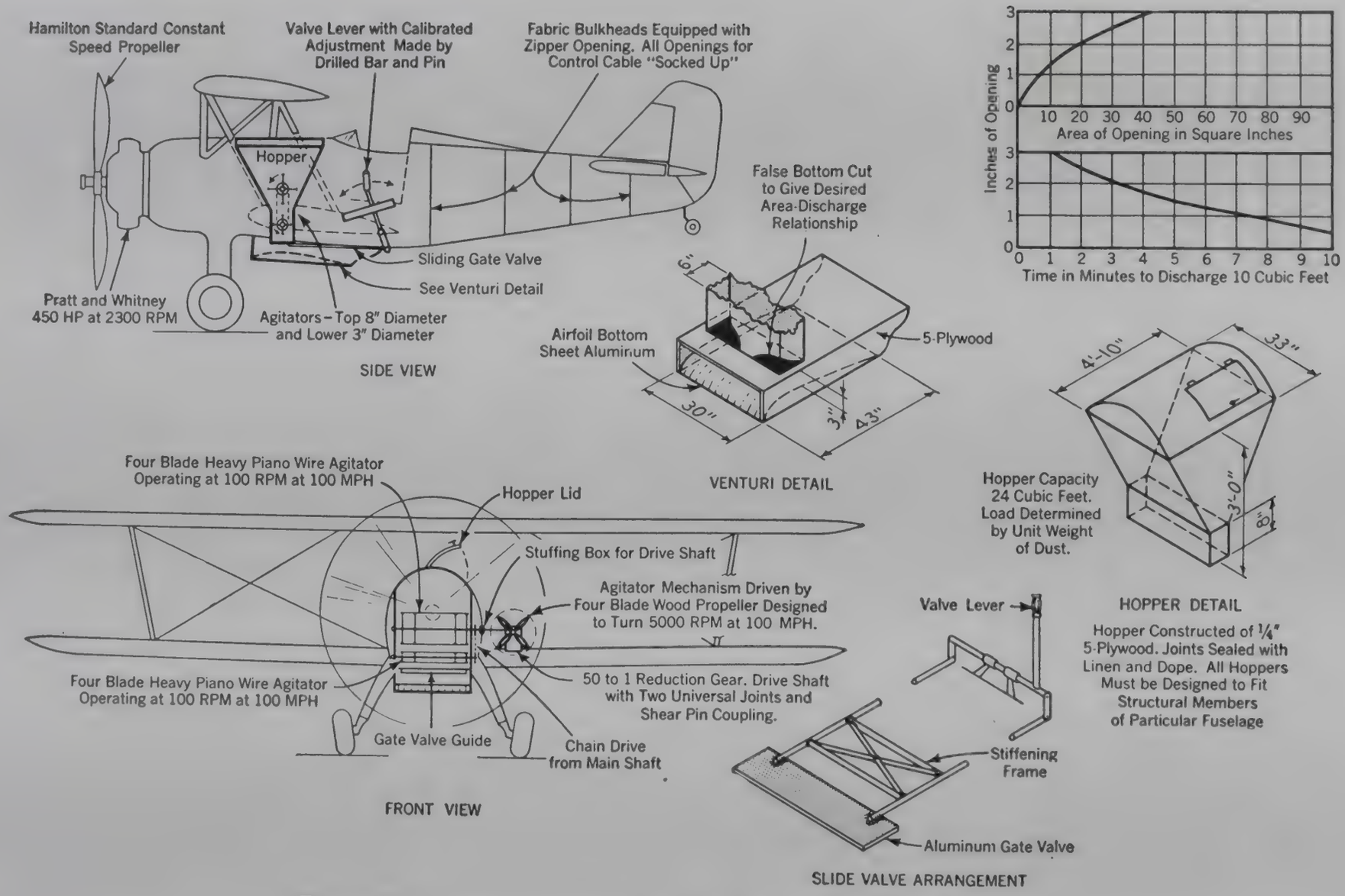
Hamilton Standard Constant Speed Propeller
Valve Lever with Calibrated Adjustment Made by Drilled Bar and Pin
Fabric Bulkheads Equipped with Zipper Opening. All Openings for Control Cable "Socked Up"
Hopper
Sliding Gate Valve
See Venturi Detail
Pratt and Whitney 450 HP at 2300 RPM
Agitators – Top 8" Diameter and Lower 3" Diameter
SIDE VIEW
False Bottom Cut to Give Desired Area-Discharge Relationship
Airfoil Bottom Sheet Aluminum
5-Plywood
30"
3"
43"
VENTURI DETAIL
Inches of Opening
Area of Opening in Square Inches
Time in Minutes to Discharge 10 Cubic Feet
4'-10"
33"
3'-0"
8"
Hopper Capacity 24 Cubic Feet. Load Determined by Unit Weight of Dust.
HOPPER DETAIL
Hopper Constructed of 1/4" 5-Plywood. Joints Sealed with Linen and Dope. All Hoppers Must be Designed to Fit Structural Members of Particular Fuselage
Four Blade Heavy Piano Wire Agitator Operating at 100 RPM at 100 MPH
Hopper Lid
Stuffing Box for Drive Shaft
Agitator Mechanism Driven by Four Blade Wood Propeller Designed to Turn 5000 RPM at 100 MPH.
Four Blade Heavy Piano Wire Agitator Operating at 100 RPM at 100 MPH
50 to 1 Reduction Gear. Drive Shaft with Two Universal Joints and Shear Pin Coupling.
Gate Valve Guide
Chain Drive from Main Shaft
FRONT VIEW
Valve Lever
Stiffening Frame
Aluminum Gate Valve
SLIDE VALVE ARRANGEMENT

FIGURE 86.—Schematic diagram of a Stearman Model 4-DX airplane equipped for application of larvicidal dusts.

attached to the dust container. Dust should be of the same shipment to insure equal density.

The principal source of inefficiency in airplane dusting with paris green results from failure of the dust to reach the treatment area. Under favorable weather conditions, only about 20 percent of the paris green released falls in the central 100 feet with another 8 percent falling in the second 100 feet of the swath section; the remainder drifts away from the treatment area and for practical purposes may be considered lost. The use of paris green of larger particle size than that commonly supplied for agricultural use has increased the recovery over a 200-foot swath from 27 percent to 43 percent. (See specifications for paris green, appendix C.) A method for checking surface recovery of paris green is given in appendix F.

Paris green does not effectively penetrate heavy vegetation and should not be depended upon to control mosquitoes in uncleared timbered areas. Paris green should be discharged at a rate of 1 to 2 pounds per acre depending upon the vegetative cover. Figure 88 shows effective swath widths in feet giving 70-percent and 90-percent larval kill under varying conditions of plant cover, rates of discharge, and distances between swaths.

DDT dust.—Dusting with DDT presents no significant departure from the paris green operation. Identical dusting equipment, loading methods, and flight techniques can be used. In general, a 5-percent mixture of DDT and soapstone is recommended as greater concentrations of DDT tend to cake and to disperse unevenly. Ten-percent

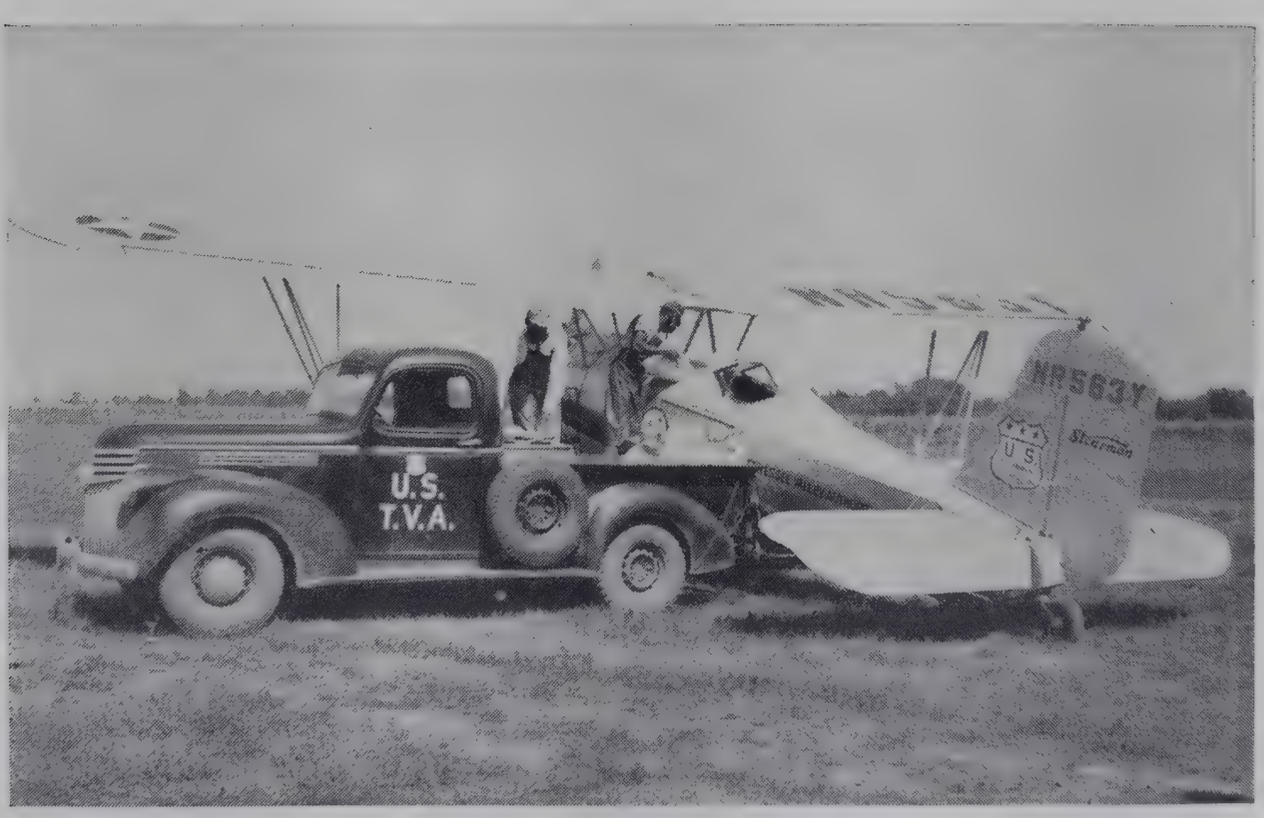

FIGURE 87.—Loading paris green dust into airplane.

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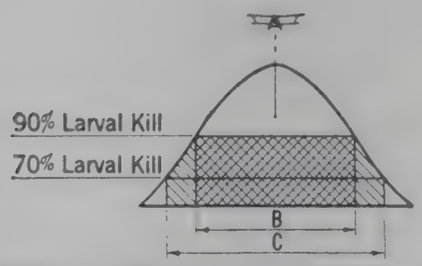
B-Width in Feet Giving at Least 90% Kill

C-Width in Feet Giving at Least 70% Kill



Required Recovery of Paris Green on Open Water Surface in Pounds per Acre			
	Plant Cover		
	Light	Medium	Heavy
90% Larval Kill	0.2	0.6	1.2
70% Larval Kill	0.1	0.3	0.6

Swath Treatment	Rate of Discharge of Paris Green in Pounds per Acre for 100 Foot Swath									Anopheles Larval Kill in Percent
	Light Cover			Medium Cover			Heavy Cover			
	1.0	1.5	2.0	1.0	1.5	2.0	1.0	1.5	2.0	
	Width of Larval Kill in Feet									
	50	90	115	0	0	20	0	0	0	At Least 90% Kill (B)
	115	160	180	20	50	80	0	0	20	At Least 70% Kill (C)
200′	115	240	300	0	0	40	0	0	0	At Least 90% Kill (B)
	300	350	380	40	115	175	0	0	40	At Least 70% Kill (C)
100′	160	210	230	0	0	40	0	0	0	At Least 90% Kill (B)
	230	255	280	40	160	200	0	0	40	At Least 70% Kill (C)
50′	130	170	190	0	55	90	0	0	0	At Least 90% Kill (B)
	190	230	265	90	130	155	0	30	90	At Least 70% Kill (C)

FIGURE 88.—Effective swath widths for airplane dusting with paris green under varying conditions of plant cover, rates of discharge, and distances between flights.

DDT-soapstone mixes are available commercially, and these may be of value in increasing the range of operation for airplanes of limited pay load. The DDT should be discharged at rates ranging from 0.1 pound per acre per 100-foot swath for light vegetative cover to 0.2 pound per acre in heavy cover. The specific gravity of the individual DDT particles is only about one-half that of paris green and, consequently, it is more affected by wind drift than is paris green. The results of laboratory and field tests on anopheline larvae have shown that DDT applied in dust form is approximately 10 times as toxic as is paris green. Table 19 lists the width of 90-percent larval kill obtained with a single-swath treatment under varying conditions of plant cover and discharge rates.

Five percent DDT in talc weighs about 40 to 50 pounds per cubic foot depending on the specific gravity of the soapstone used. The weight of DDT per cubic foot of mixed dust is used as in the case of paris green to determine the correct valve setting for the desired rate of application in pounds of DDT per acre.

Airplane application of liquid larvicides

With the advent of DDT, an oil soluble material more toxic than any previously discovered larvicide, the distribution of liquid larvicides by airplane has become feasible. This method of distribution has several advantages over the use of dusts: particle size can be controlled in the design and operation of the dispersal equipment; the liquid carrier will spread upon the water surface and will penetrate the body of the mosquito larva; and the oil film on the water surface is nonsinkable, and is not disturbed by wind and wave action to the same extent as are dust particles.

TABLE 19.—*Rates of discharge and effective swath widths for DDT dusting in various types of plant cover*

	Vegetative cover		
	Light	Medium	Heavy
Rates of discharge of DDT in pounds per acre	0.1 *to* 0.2	0.1 *to* 0.2	0.1 *to* 0.2
Width of 90-percent larval kill in feet	125 *to* 180	20 *to* 80	0 *to* 20

TABLE 20.—*Comparative cost of airplane application of paris green and DDT dusts*

Dust used—1,000-pound load	Paris green, 20 percent	DDT, 5 percent
Application rate	2.0 pounds per acre	0.2 pound per acre.
Acres covered by plane load	100	250.
Costs per acre:		
Plane flying time and stand-by	$0.18	$0.12
Loading	$0.05	$0.02
Materials[1]	$0.50	$0.16
Inspections	$0.06	$0.06
Total cost per acre	$0.79	$0.36

[1] Cost of materials:

	Per pound
Soapstone	$0.005
Paris green	0.20
DDT	0.50

The number of particles which will result from the break-up of a given weight of liquid larvicide is inversely proportional to the cube of the diameter of the particle. This consideration is important in the determination of the minimum rate of larvicidal application necessary to give surface coverage adequate to kill the larvae. The following table shows the number of droplets formed from a uniform application of 0.1 pound of DDT per acre as a 20-percent solution in Velsicol NR-70 (tetramethyl naphthalene).

TABLE 21.—*Theoretical numbers of spray droplets of varying particle sizes which can be formed from 0.1 pound of DDT per acre as a 20-percent solution in Velsicol NR-70*

Particle diameter in microns	Particle weight in micrograms	Number of particles per acre	Number of particles per square centimeter
5	0.07×10^{-3}	$2{,}900 \times 10^{9}$	72,000
25	9×10^{-3}	23×10^{9}	580
50	70×10^{-3}	2.9×10^{9}	72
100	600×10^{-3}	0.37×10^{9}	9

Thus, from the standpoint of adequacy of distribution, the smaller the droplets the more adequate the coverage.

Where settling rates are concerned, however, the converse is true. The settling rates of small spherical particles in still air are directly proportional to the square of the particle radius. The rate of fall of droplets of 20-percent DDT in Velsicol NR-70 in motionless air is given in table 22.

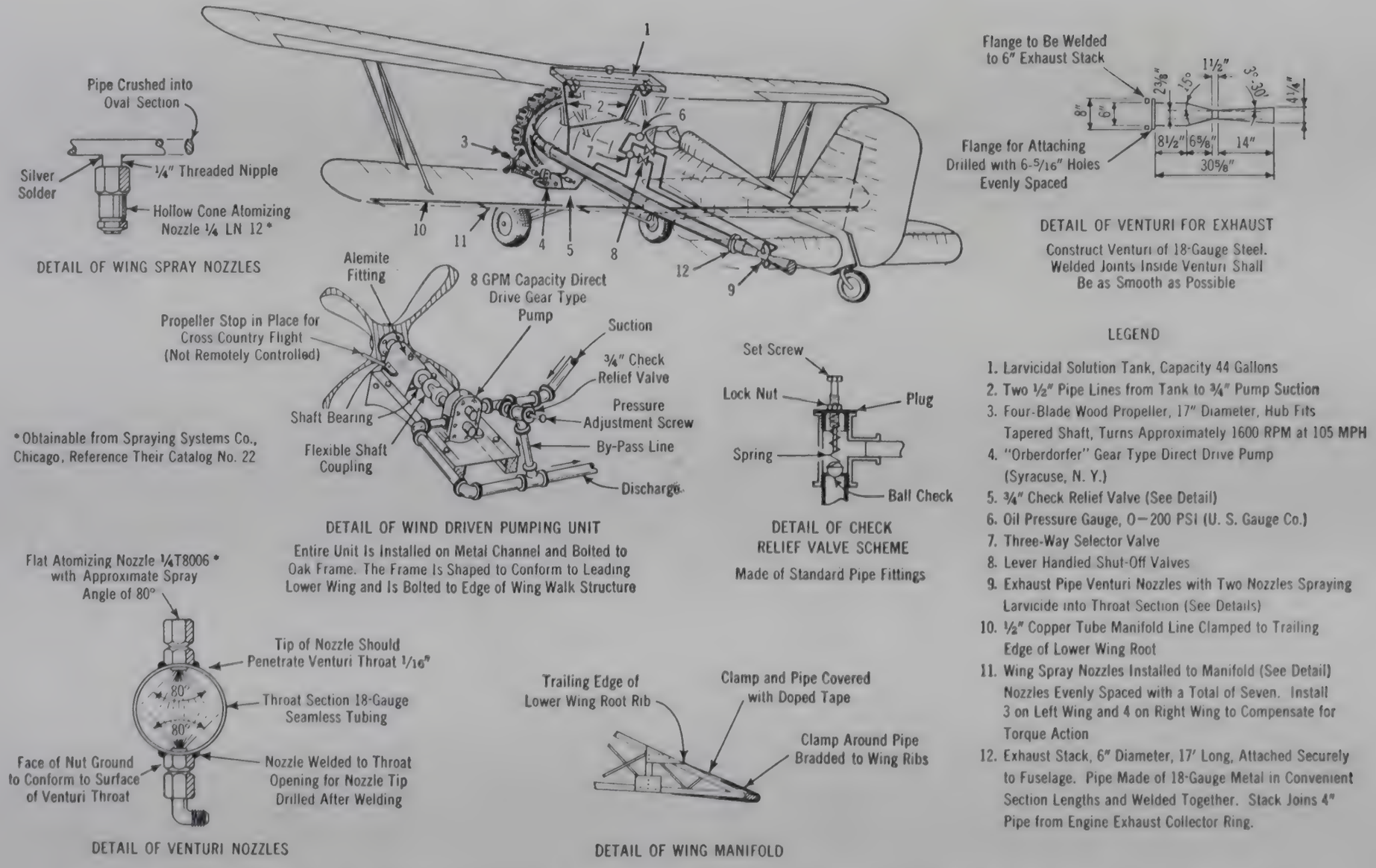

Pipe Crushed into Oval Section
Silver Solder
¼" Threaded Nipple
Hollow Cone Atomizing Nozzle ¼ LN 12 *
DETAIL OF WING SPRAY NOZZLES
* Obtainable from Spraying Systems Co., Chicago, Reference Their Catalog No. 22
1
2
3
4
5
6
7
8
9
10
11
12
Alemite Fitting
8 GPM Capacity Direct Drive Gear Type Pump
Propeller Stop in Place for Cross Country Flight (Not Remotely Controlled)
Suction
¾" Check Relief Valve
Pressure Adjustment Screw
By-Pass Line
Discharge
Shaft Bearing
Flexible Shaft Coupling
DETAIL OF WIND DRIVEN PUMPING UNIT
Entire Unit Is Installed on Metal Channel and Bolted to Oak Frame. The Frame Is Shaped to Conform to Leading Lower Wing and Is Bolted to Edge of Wing Walk Structure
Set Screw
Lock Nut
Plug
Spring
Ball Check
DETAIL OF CHECK RELIEF VALVE SCHEME
Made of Standard Pipe Fittings
Flange to Be Welded to 6" Exhaust Stack
Flange for Attaching Drilled with 6-5/16" Holes Evenly Spaced
8"
6"
2⅜"
1½"
15°
30°
4¼"
8½"
6⅝"
14"
30⅝"
DETAIL OF VENTURI FOR EXHAUST
Construct Venturi of 18-Gauge Steel. Welded Joints Inside Venturi Shall Be as Smooth as Possible
LEGEND
1. Larvicidal Solution Tank, Capacity 44 Gallons
2. Two ½" Pipe Lines from Tank to ¾" Pump Suction
3. Four-Blade Wood Propeller, 17" Diameter, Hub Fits Tapered Shaft, Turns Approximately 1600 RPM at 105 MPH
4. "Orberdorfer" Gear Type Direct Drive Pump (Syracuse, N. Y.)
5. ¾" Check Relief Valve (See Detail)
6. Oil Pressure Gauge, 0—200 PSI (U. S. Gauge Co.)
7. Three-Way Selector Valve
8. Lever Handled Shut-Off Valves
9. Exhaust Pipe Venturi Nozzles with Two Nozzles Spraying Larvicide into Throat Section (See Details)
10. ½" Copper Tube Manifold Line Clamped to Trailing Edge of Lower Wing Root
11. Wing Spray Nozzles Installed to Manifold (See Detail) Nozzles Evenly Spaced with a Total of Seven. Install 3 on Left Wing and 4 on Right Wing to Compensate for Torque Action
12. Exhaust Stack, 6" Diameter, 17' Long, Attached Securely to Fuselage. Pipe Made of 18-Gauge Metal in Convenient Section Lengths and Welded Together. Stack Joins 4" Pipe from Engine Exhaust Collector Ring.
Flat Atomizing Nozzle ¼T8006 * with Approximate Spray Angle of 80°
Tip of Nozzle Should Penetrate Venturi Throat 1/16"
80°
80°
Throat Section 18-Gauge Seamless Tubing
Face of Nut Ground to Conform to Surface of Venturi Throat
Nozzle Welded to Throat Opening for Nozzle Tip Drilled After Welding
DETAIL OF VENTURI NOZZLES
Trailing Edge of Lower Wing Root Rib
Clamp and Pipe Covered with Doped Tape
Clamp Around Pipe Bradded to Wing Ribs
DETAIL OF WING MANIFOLD

FIGURE 89.—Diagram of an airplane equipped for distribution of liquid larvicides as sprays or as thermal aerosols.

TABLE 22.—*Theoretical settling rate of 20-percent DDT-Velsicol NR-70 droplets in still air based on Stokes' law*

Diameter of droplets in microns	Rate of fall in feet per minute	Diameter of droplets in microns	Rate of fall in feet per minute
1.....	0.007	50.....	17
5.....	.17	100.....	68
25.....	4.2	200.....	270

Thus it may be seen that droplets under 50 microns diameter are relatively stable in still air and may be considered, by definition, as aerosols.

These aerosol particles could not be successfully deposited by airplane treatment if it were not for the downdraft of air which occurs in the wake of an airplane. This downdraft imparts settling velocities to the small aerosal particles which are greatly in excess of their normal settling rates. Measurements of the downdraft from the Stearman 4-DX biplane indicate that it is of the order of 600 feet per minute.

In practice it has been found that aerosols distributed from low flying airplanes produce more uniform swath distribution than do relatively coarser sprays which "peak" badly. This is apparently due to the fact that the small aerosol particles are more responsive to the whirling motion of the propeller torque and thus have greater lateral drift.

In general, the same types of aircraft used for dusting can be converted for dispersal of liquid larvicides by substituting a tank for the dust hopper, a wind-driven gear pump for the wind-driven agitator, and atomizing nozzles or venturi for breaking up the liquid in place of the dust venturi. The types of equipment which have proved successful for the breaking up of liquid larvicides are shown in figure 89.

Sprays.—Liquid larvicides may be applied by a spraying system of atomizing nozzles located along the trailing edge of the wing. The break-up of the liquid is attained by action of the nozzles plus the air velocity over the wing surface. In figure 90, four of the atomizing nozzles along the wing may be observed discharging a mistlike cloud. This type of equipment gives liquid droplets with a mean mass diameter ranging from 200 to 400 microns. Spraying pressures of 50 to 100 pounds per square inch seem most suitable. An atomizing nozzle capable of discharging 12 gallons of water per hour at 40 pounds of pressure will meet the requirements for DDT-Velsicol solutions. The number of these nozzles necessary for adequate distribution of a 20-percent solution of DDT at a rate of 0.1 pound DDT per acre with 100-foot swaths may be determined as follows:

$$\text{Number of nozzles} = 0.066 \times (\text{cruising speed in m.p.h.})$$

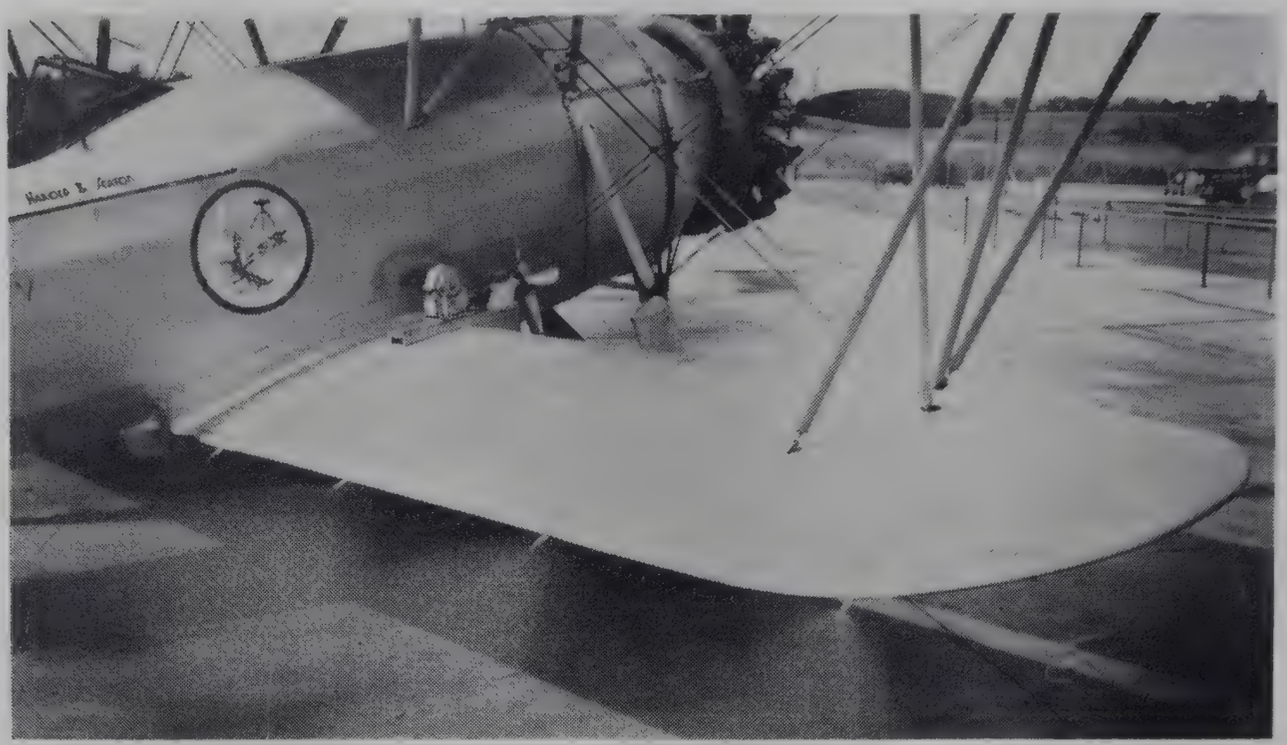
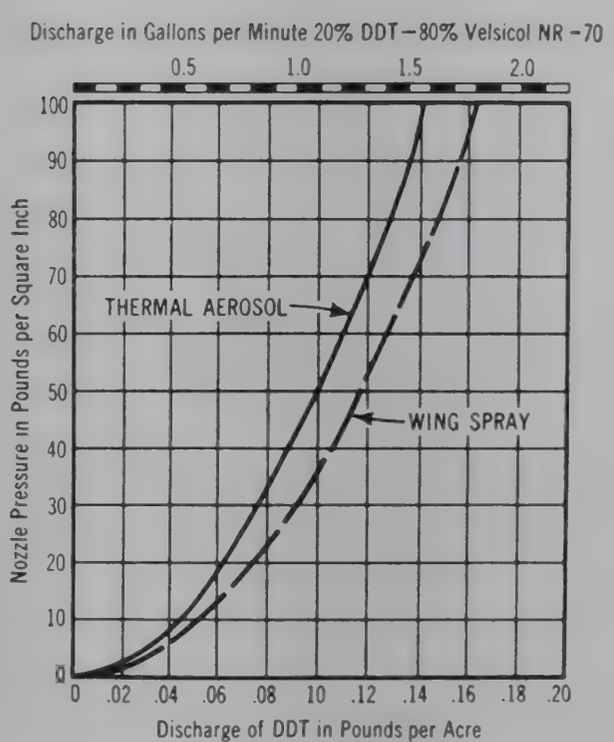


FIGURE 90.—Wing spray nozzles in operation.



DATA

Calibrated at Temp.	75°-80° F
Assumed Swath Width	100 Ft
Application Speed	105 MPH
Rate of Coverage	21 Acres per Min
Weight of Larvicidal Solution Per Gallon	9.35 Lbs
Weight DDT per Gallon	1.87 Lbs
450 HP Stearman NR 792H	

FIGURE 91.—Calibrations of equipment for application of sprays and thermal aerosols.

The rate of discharge of the individual nozzles is governed by the solution pressure and is used as the basis for calibrating rates of application. (See fig. 91.) The wind-driven pumping unit (see appendix E for design of propellers) should have a capacity in excess of actual requirements. By installing a simple bypass and adjustable pressure relief valve, any desired pressure or discharge may be maintained.

Figure 92 shows a view of the propeller, gear pump, and bypass piping, mounted as a unit on the leading edge of the lower wing. This type of system gives a high recovery of the material discharged and is especially useful under windy conditions. It has the disadvantage that the larger droplets produced do not penetrate heavy vegetation as readily as do aerosols. Also, a very large percentage of the material recovered is in the central 20 to 40 feet of the swath where the deposit is much in excess of larvicidal requirements and may be considered wasted. Furthermore, the spray is almost invisible and the pilot may have difficulty in ascertaining the area treated. This is not true of dust or aerosol (smoke) clouds which may readily be seen.

Until the wing spray equipment is further developed, the mass of DDT recovered will not be as significant an indicator of expected larval kill as the number of particles per unit area.

The following table shows the widths of 90-percent larval kill

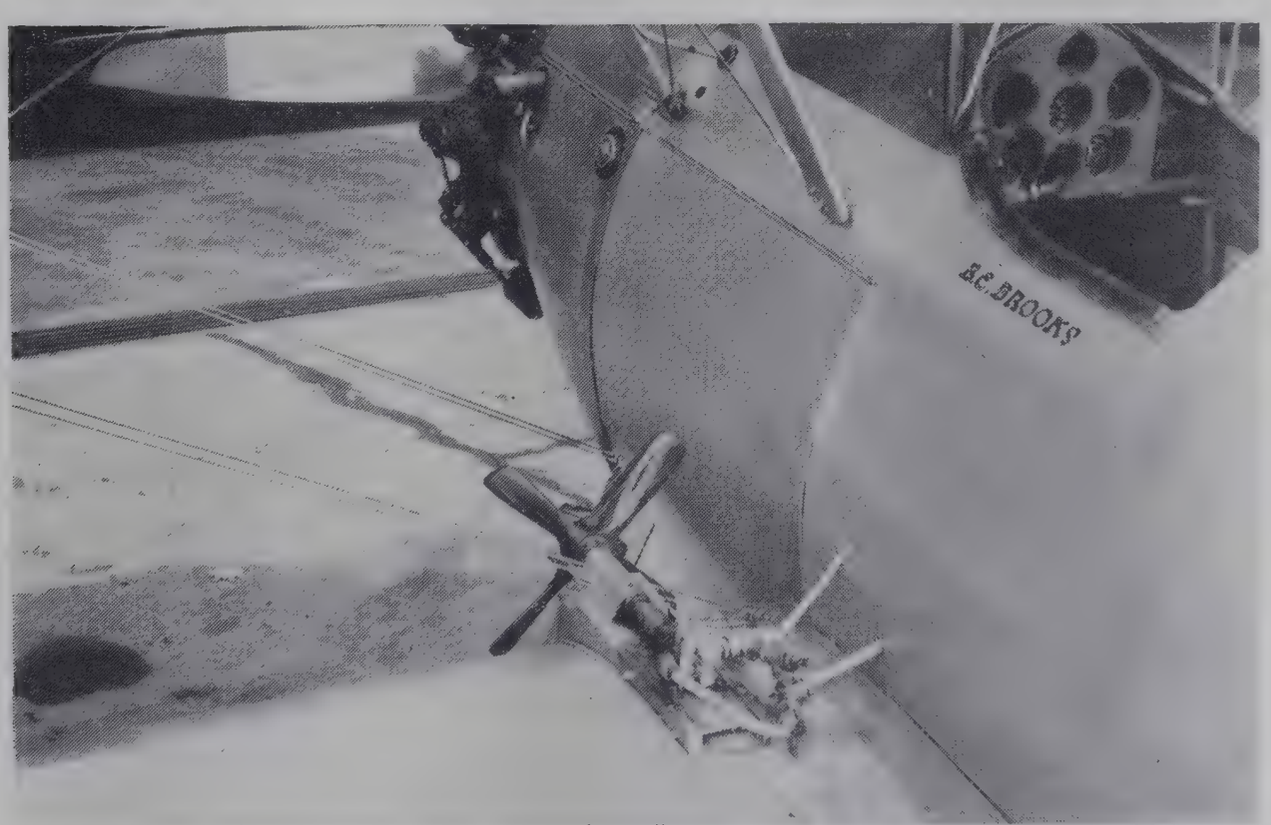


FIGURE 92.—Propeller, gear pump, and bypass piping for spray and aerosol equipment.

FIGURE 93.—DDT aerosol droplets on water surface.

obtained with a wing spray at a discharge rate of 0.1 pound DDT per acre in varying degrees of plant cover and swaths treated.

TABLE 23.—*Widths of 90-percent larval kill obtained by wing spray equipment at 0.1 pound of DDT per acre (100-foot swaths) in varying degrees of plant cover*

	Swath treatment					
	Single			Two swaths (100 feet apart)		
Vegetative cover	Light	Medium	Heavy	Light	Medium	Heavy
Width of 90-percent larval kill in feet	155	120	20	260	220	100

Aerosols.—Liquid larvicides may also be applied as aerosols by the injection of the solution into a high velocity stream of exhaust gases. The heated exhaust gases from the airplane engine, at about 1,000° F. (538° C.), are led through an elongated exhaust pipe to a venturi where their velocity is increased six to eight times. This hot stream of gases at high velocity breaks up the oil solution sprayed into the venturi throat into very small particles of aerosol dimensions (less than 50 microns in diameter). These very small droplets are comparable to dust particles in size, yet spread well when they reach the water surface. (See fig. 93.) The exhaust gas velocities required for adequate liquid break-up with the unit illustrated in figure 89 are in the neighborhood of 600 feet per second. In order to compute the diameter of the venturi throat required to give this velocity it is

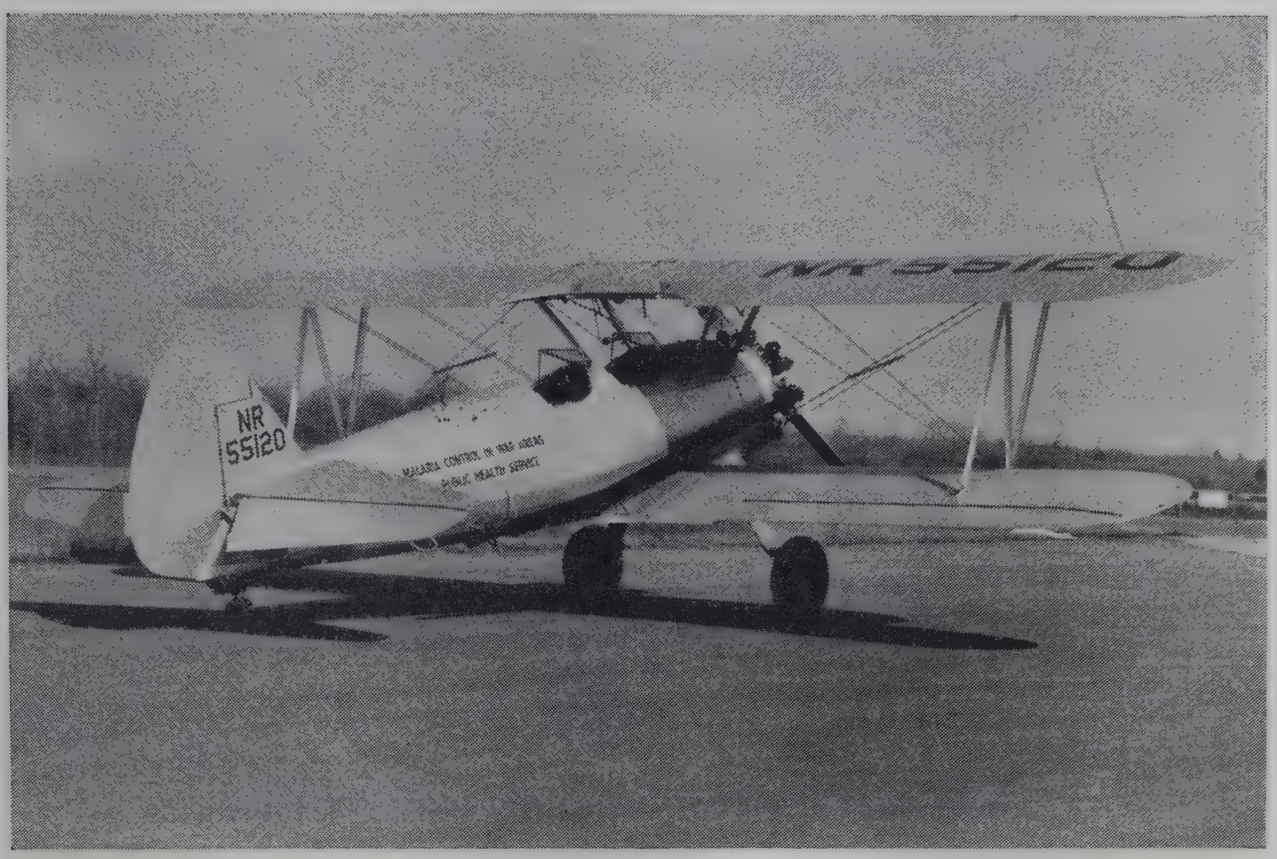


FIGURE 94.—PT-17 equipped with exhaust stack and venturi for larviciding with DDT aerosols.

necessary to know the volume of exhaust gases available from operation of the engine. A method for estimating the volume of exhaust gases produced at 1000° F. by an airplane engine is given in appendix E.

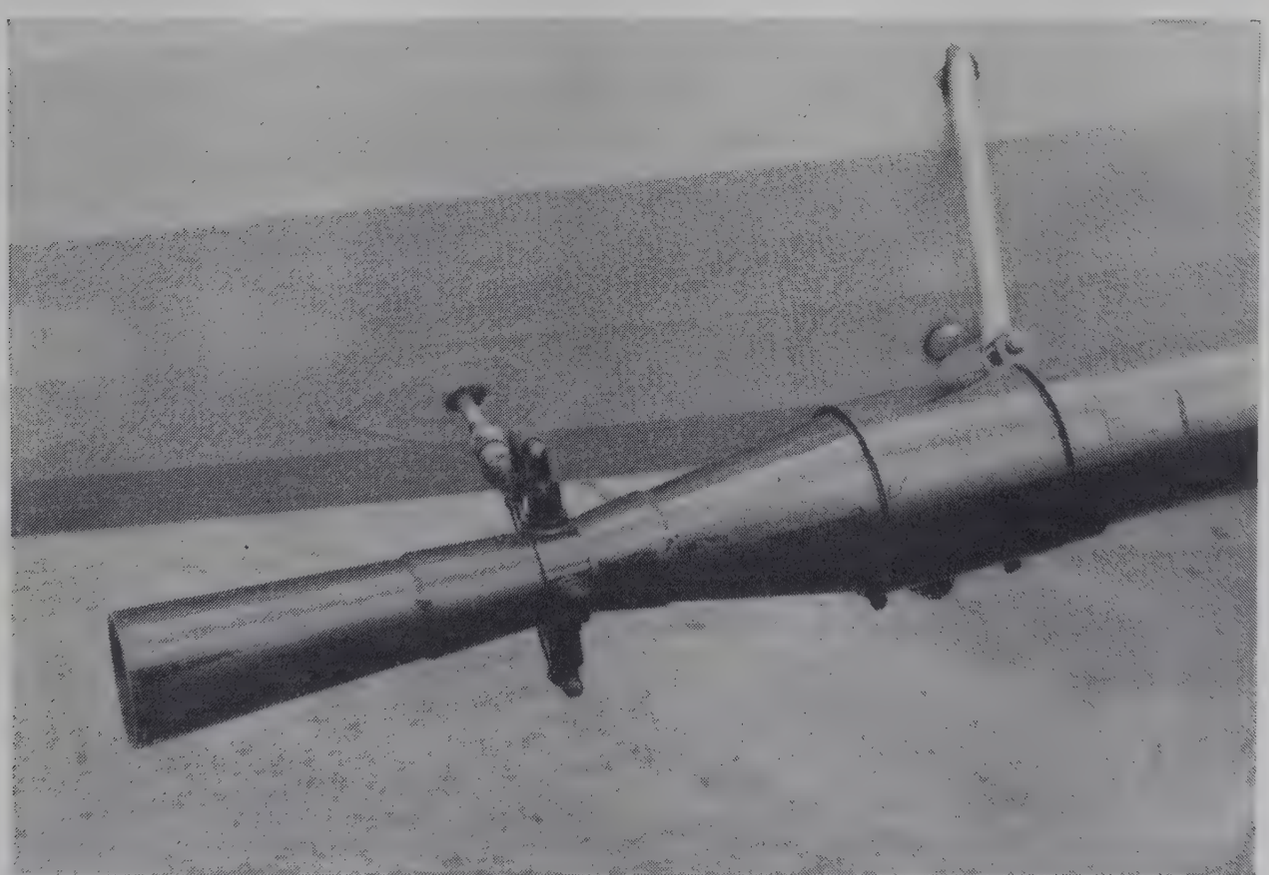


FIGURE 95.—Close-up of venturi showing nozzles and mounting.

FIGURE 96.—Air view of application of DDT aerosol.

Figure 94 shows the exhaust pipe extension and venturi assembly on a 220–hp. Stearman PT–17. Note points of attachment which rigidly secure the equipment against vibration. Figure 95 is a close view of the same equipment showing the detail of the machined venturi throat and nozzle arrangement. By properly designing the venturi, the back pressures (10 to 20 inches of water) built up by the constriction will be insignificant. Experience has shown that these back pressures are harmless to the engine. The length of the venturi recovery section should be as short as is commensurate with reasonable back pressures in order to prevent the condensation of droplets into large particles. In the operation of the venturi generator, the particle size produced depends upon the velocity of the exhaust gas, volume of exhaust gas, rate of liquid feed, and type of solvent used. Temperature is not normally a factor because of the relatively constant temperatures of exhaust gases. High-boiling solvents such as the methylated naphthalenes are most satisfactory as they are not readily volatilized at exhaust temperatures. (See table 17.) In the generator described (fig. 89) the mass median diameter of the droplets produced can be varied from 25 to 100 microns depending on engine r.p.m., the rate of liquid feed, and the type of nozzle used in the venturi throat. The liquid and gas flow relationships required to give the desired particle size (median diameter-mass) may be estimated from the following empirical formula:

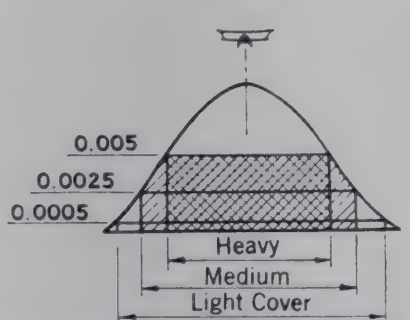
$$\text{Median diameter}—D=\frac{Q_L \times A_T \times 10^7}{0.055 \times Q_G^2}-4$$

D = Median particle diameter (mass) in microns
Q_L = Rate of liquid injection (cfs.)
A_T = Area of venturi throat (sq. ft.)
Q_G = Gas flow (cfs. at 1,000° F.)

This formula is applicable only to the type of equipment illustrated in figure 89 and for a 20 percent DDT solution of Velsicol NR-70. Approximately one-fourth of the solvent is volatilized to form visible smoke which is larvicidally ineffective but forms a very convenient marker (fig. 96). The DDT concentration in the oil droplets is thus increased from 20 to about 25 percent. The advantages of the aerosol application are (1) the relative lack of peaking in the swath cross section which reduces overdosage and thereby decreases toxicity to wildlife; (2) the enormous number of droplets produced per unit volume of material used which increases the swath width and gives better penetration of vegetation (see table 21); and (3) the presence of a smoke marker to guide the pilot. The percent recovery of material is smaller, however, with this type of application than with the larger particle size sprays. A method for checking surface recovery of aerosol or spray deposits is given in appendix F.

For both methods of application the early morning hours are recommended. Flights should preferably be made at altitudes of 20 to 30 feet. However, in certain situations, such as wooded areas,

Data Based on Distribution of 20% DDT—80% Velsicol Aerosol with Mean Mass Diameter of 35-40 Microns



Required Recovery of DDT on Open Water Surface in Pounds per Acre To Give 90% Anopheles Larval Kill		
Plant Cover		
Light	Medium	Heavy
0.0005	0.0025	0.005

Swath Treatment	Rate of Discharge of DDT in Pounds per Acre for 100′ Swath								
	Light Cover			Medium Cover			Heavy Cover		
	0.05	0.1	0.2	0.05	0.1	0.2	0.05	0.1	0.2
	Width of 90% Larval Kill in Feet								
	180	200	240	65	120	170	10	60	115
200′	380	410	450	130	240	370	20	120	230
100′	270	300	335	160	225	270	30	160	215
50′	230	250	290	110	170	220	55	110	170

FIGURE 97.— Effective swath widths for airplane application of DDT aerosol under varying conditions of plant cover, rates of discharge, and distances between flights.

effective control has been achieved when flying at heights of 100 feet. The rate of discharge should be from 0.05 to 0.2 pound of DDT per acre per 100-foot swaths depending on the vegetative cover. The recommended treatment rates, effective swath widths, and intervals between swaths are indicated in figure 97. A recovery of the aerosol at 0.0005 pound DDT per acre (in the open) is adequate to give 90 percent anopheline larval kill in light plant cover. This is represented by approximately two droplets per square centimeter. For conditions of medium plant cover 0.0025 pound of DDT per acre is required to give 90 percent kill, and for heavy cover 0.005 pound of DDT per acre is necessary.

HAND AND POWER APPLICATION OF LARVICIDAL DUSTS

Hand dusting

The chief advantages of hand dusting are the lower initial costs and the adaptability for use in small or inaccessible areas. Standard commercial hand rotary dusters commonly used for crop dusting (appendix D) are suitable for hand larviciding. A popular model weighing 12 pounds holds 600 cubic inches of dust or about 18 to 20 pounds of larvicidal dust. A sliding valve regulates the rate of discharge. For uniform flow the duster should be provided with some device in the hopper that will keep the dust constantly agitated and in a light and fluffy condition. The hopper may best be loaded with an ordinary drinking water dipper. In order to prevent strain or fatigue when cranking it is important that the equipment be adjusted to the body of the operator. When one considers the irritating effect of arsenical dusts and the poor footing of terrain, the operation of a hand duster is an unpleasant and laborious task. A dust respirator cannot practically be worn because of the strenuous nature of the work. In using irritating dusts, such as paris green, the use of canvas aprons, followed by showers and changes of clothing at the end of the day's operation, will greatly reduce dermatitis problems.

The amount of paris green usually used in a dust for hand equipment ranges from 5 to 15 percent mixed with soapstone. DDT dust for hand larviciding should contain 1 to 2 percent DDT. Effective rates of application are approximately 1 pound of paris green per acre or 0.1 pound DDT per acre. The rates of application are lower than those required for airplane dusting because the recovery is better in ground application. The effectiveness of hand dusting is dependent upon the skill of the operator in utilizing wind drift to obtain a satisfactory distribution. (See fig. 98.) In moderate

winds, swaths up to 200 feet can be treated. In breezes less than 2 miles per hour, and in treating broad areas, the operator should walk at a normal pace with the nozzle well elevated. As the paris green in the cloud is 3 times as heavy as the diluent, it settles out more quickly, and the effectiveness of the treatment does not extend to the limit of the visible cloud. DDT is only slightly heavier than the diluent and the effectiveness of the treatment will extend nearly to the limit of the cloud.

Power dusting

Power-dusting equipment is generally mounted in a boat or on a truck bed. These devices make possible the control of anopheline breeding areas too large for hand dusting. Power-dusting units may have hopper capacities ranging from 25 to 100 pounds and weigh from 150 to 400 pounds with engines varying from 1¾ to 6½ hp. (See appendix D for specifications.) These units will develop air velocities up to 250 feet per second which are beneficial in "setting up" the dust cloud (fig. 99). With ideal breezes, power-dusting equipment can treat the water surface up to 500 feet away from the point of application. However, considerable skill is required by the operator to avoid leaving untreated areas. Breeding areas should be studied in advance to plan effective treatment under varying wind directions. Treatment should not be attempted in a strong or gusty wind. On large reservoirs, breezes in the morning are usually "on shore" and change to "off shore" later in the day. Mod-

FIGURE 98.—Hand application of paris green dust.

FIGURE 99.—Application of paris green with a power duster.

erate breezes with velocities not over 7 to 8 miles per hour are most satisfactory. In breezes less than 2 miles per hour, the nozzle should be elevated considerably to reduce over-treatment near the point of discharge. For best results, the equipment should move cross-wind. Poor distribution and spotty kill will result by attempting to cover a large area from a fixed point on the edge. The recommended

TABLE 24.—*Comparative cost of paris green dusting and DDT-aerosol applied by airplane*

Material (1,000-pound load)	20-percent paris green	20-percent DDT in Velsicol NR-70
Application rate, pound per acre	2 pounds	0.1 pound
Acres covered by plane load	100	2,000.
Cost per acre:		
Plane service, flying time and standby	$0.18	$0.08.
Loading	.05	.03.
Materials[1]	.50	.09.
Inspections	.06	.06.
Total cost per acre	$0.79	$0.26.

[1] Cost of materials

	Per pound
Paris green	$0.20
Soapstone	.005
DDT	.50
	Gallon
Velsicol NR-70	.47

treatment rates are 1 pound of paris green per acre or 0.05 to 0.1 pound of DDT per acre. The paris green mixture should not have a concentration of more than 15 percent by weight. Two men, one boat or truck operator and one duster operator, are required for power dusting.

HAND AND POWER APPLICATION OF LIQUID LARVICIDES

Hand spraying

The knapsack sprayer is the most widely used hand equipment for applying liquid larvicides. Knapsack sprayers usually hold about 4 gallons of solution and weigh about 45 pounds when full. Where fuel oil or kerosene is to be used, the Bordeaux type nozzle is preferred. This gives a fan-shaped stream which can be directed in an arc from left to right by the operator so as to distribute the material in a swath 10 to 15 feet wide (fig. 100). Fuel oil is usually applied at about 20 to 40 gallons per acre depending upon the amount of vegetative cover. A great deal of time is consumed in refilling the spray cans, a task which may be best accomplished by using a common pitcher spout pump to lift the oil from the boat tanks or drums. Where trucks are used, the cans can be filled from a spigot.

DDT as a 1- to 2-percent fuel oil solution can be applied by the

FIGURE 100.—Hand application of oil larvicides.

knapsack method by using an agricultural type atomizing nozzle which will produce a mist. (See appendix D.) When applying a DDT solution by hand, the operator should take advantage of the wind drift, as in hand dusting, and should not attempt to cover the area with a heavy film, as in the case of fuel oil. The dosage should be at the rate of about 0.05 to 0.1 pound of DDT per acre in an oil solution of ½ to 2 percent with about ½ to 1 percent wetting agent added. With fuel oil alone about 10 full knapsacks are necessary to treat 1 acre of breeding area while with DDT-fuel oil mixes one knapsack full will treat 2 to 4 acres. Thus, a remarkable saving in labor and materials may be effected by using DDT and an atomizing nozzle when knapsacking.

Various types of "pump-up" cans are available which hold from 2 to 4 gallons and operate at about 40 pounds pressure. These are suitable for spraying DDT-fuel oil solutions. If larvicidal oil is applied at the rate of 1 gallon per acre, about 1 acre can be treated per "pump-up" operation of these cans. With the air pressure hand sprayers there is less danger of spilling the solution on the back of the operator. By the use of proper adaptions they can be pumped up by mobile air compressors (fig. 119).

Boat application

Breeding areas lying along a steep shore line can best be treated by boat. One of the most convenient methods is the water-oil larvi-

FIGURE 101.—Boat application of water-oil emulsion.

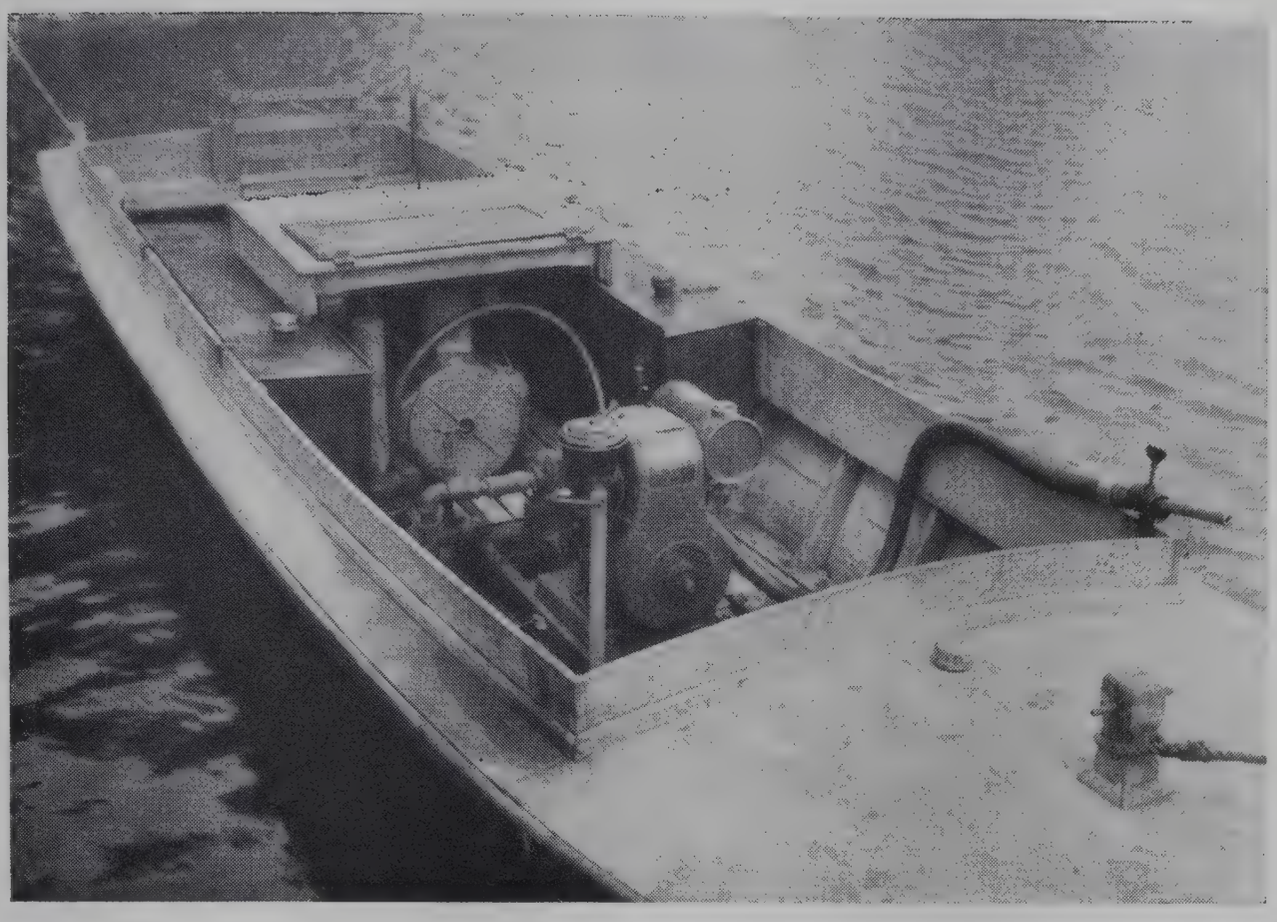


FIGURE 102.—Water-oil pumping unit mounted in an inboard motor boat.

cidal boat unit using fuel oil or kerosene. This equipment is shown in operation in figure 101 and diagramed in figure 130. It consists of a rotary pump driven by a separate engine (fig. 102) or by friction drive off the boat-propelling motor (fig. 103), taking suction from the lake and discharging the water under pressure through a hose and nozzle system. The larvicide enters the water on the suction side of the pump forming a mechanical mixture of water and oil as it goes through the pump. The emulsion is discharged through the nozzle with sufficient pressure to carry 75 to 100 feet from the unit, penetrate the vegetation and flotage, and break up any natural surface films. The pump should be of sufficient capacity to provide an approximate ratio of water to oil of 100 to 1. The "well-type" water intake and strainer provide a clean water supply when operating in shallow areas. When oil is used as a larvicide, tank storage for 50 to 150 gallons of material should be provided in the boat. The discharge hose is normally 10 feet long but under special conditions may be much longer. The valve on the larvicide feed line should be conveniently located so that the operator may rapidly change the rate of application commensurate with the breeding situation encountered. Where black oil is added to the larvicidal oil, the operator can gauge the rate of application by the color of the water stream. Both inboard and outboard powered equipment may be used. The outboard unit is light, more maneuverable, and

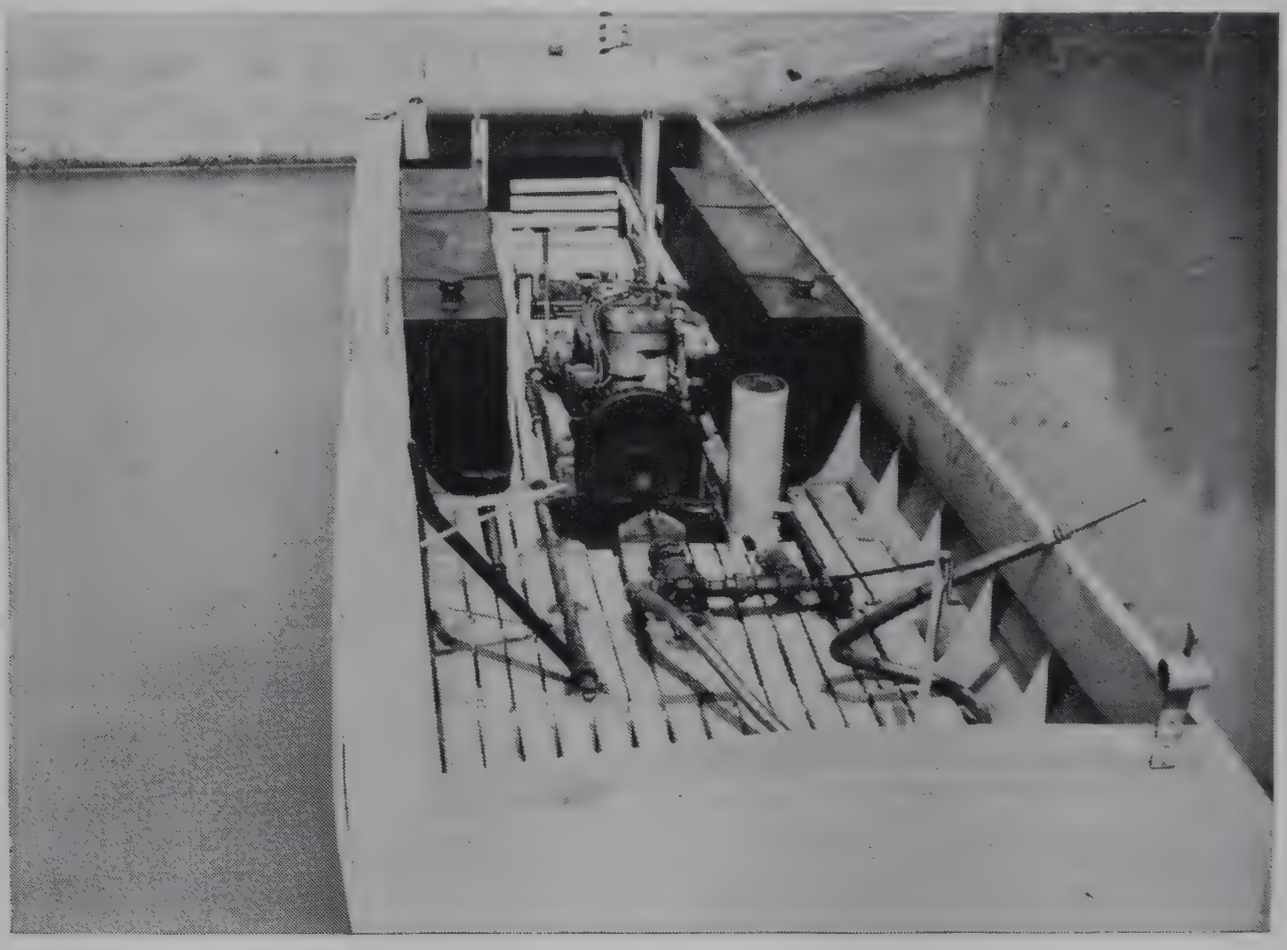


FIGURE 103.—Water-oil friction-drive pumping unit mounted in an inboard motor boat.

operates easily in shallow water; however, an engine pumping unit must be provided. The inboard units are the most reliable. They may be equipped with a friction-drive pump. (See fig. 103.) The inboard units are especially adapted to supplementary use for herbicidal work, transportation of men and tools, and other malaria control operations.

The use of 1- to 5-percent DDT-fuel oil mixture applied at about 0.05 to 0.1 pound DDT per acre will effect a tremendous saving in materials for boat oiling. On the basis of tank capacity, the range of operation for a 140-gallon oil unit is increased from 4 miles of shore line breeding area to 400 miles with more effective control of anopheline and culicine mosquitoes. The same type of water-oil equipment, modified to provide a "sight-feed" and a small orifice, may be used to apply DDT-fuel oil larvicides. (See fig. 202.)

Truck application

Other types of mechanical sprayers have been successfully used. Among these are the "paint-gun" types mounted on trucks, using air under pressure to break up the liquid into a mist. This type of equipment is well suited for DDT-fuel oil dispersal. A unit using a jeep or truck equipped with an exhaust venturi has been experimented with for distributing DDT-oil solutions as a mist or aerosol, but possesses the same limitation of cloud control inherent in all

surface equipment. Five- to 55-gallon tanks may be installed so that the solution will feed by gravity into a venturi on the end of a flexible tube connected with the exhaust line. The particle size produced from a 5 percent DDT-fuel oil solution or 20 percent DDT-methylated naphthalene solution is dependent upon the engine speed and the rate of liquid flow and may vary from an aerosol to a coarse spray.

COST AND EFFICIENCY OF DUST VS. LIQUID LARVICIDES

Generally, larvicidal oiling methods are more effective than dusting. This is principally due to the type of areas treated and lack of uniformity in dust distribution. Dusting is most adaptable to "block acreage" while oiling is better suited to "strip acreage." Tables 25 and 26 give some relative costs for the various ground methods of larviciding.

TABLE 25.—*Cost*[1] *of hand treatment methods.*

Material used	Dusts		Liquids	
	Paris green, 15 percent	DDT, 2 percent	Fuel oil	DDT-fuel oil, 1 percent
Rate applied (active ingredient)	1 pound/acre.	0.05 to 0.1 pound/acre.	30 gallons/acre.	0.05 to 0.1 pound/acre.
Acres treated (per man-day)	10 acres	10 acres	2 acres	10 acres.
Cost per acre:				
Labor[2]	$0.48	$0.48	$2.40	$0.48.
Materials	$ .29[3]	$ .13[3]	$3.00	$ .14[4].
Total per acre	$0.77	$0.61	$5.40	$0.62.

[1] Costs do not include overhead, supervision, or transportation.
[2] Labor cost on basis of $0.60 per hour.
[3] 1 cent for mixing and bagging per pound.
[4] 2 cents for mixing solution per gallon.

TABLE 26.—*Cost of power treatment by boat.*

Materials used	Dusts		Liquids	
	Paris green, 15 percent	DDT, 2 percent	Fuel oil	DDT-fuel oil, 1 percent
Rate applied (active ingredient)	1 pound/acre.	0.05 to 0.1 pound/acre.	30 gallons/acre.	0.05 to 0.1 pound/acre.
Acres treated (per unit per day)	15 acres	15 acres	5 acres	5 acres.
Cost per acre:				
Labor[1]	$0.70	$0.70	$2.08	$2.08.
Materials	$ .29	$ .13	$3.00	$ .14.
Stand-by[2]	$ .03	$ .03	$ .08	$ .08.
Total	$1.02	$0.86	$5.16	$2.30.

[1] 2-man boat crew on basis of $1.30 per hour.
[2] Maintenance on boats for larvicidal work, $0.40 per day.

ADULTICIDING WITH DDT SPRAYS AND AEROSOLS

Although the possibilities of adulticiding for malaria control on impounded waters are largely unexplored, it appears that at present such treatment should be regarded as purely an emergency measure to be used only where immediate relief is desired from mosquito biting or epidemic malaria. The measure consists of the application of the insecticide to forested areas, barns, and other structures, which serve as daytime resting places for adult anophelines. When properly performed, the operation is astonishingly effective, resulting in better than 90 percent reduction of adult mosquitoes in the area treated within 1 to 2 hours after application where aerosols are applied, and within 24 hours where coarse residual sprays are used. The disadvantages of the operation as compared to larviciding are (1) higher dosages of insecticide are required; (2) the areas requiring treatment are more extensive and less well defined; and (3) the danger of killing useful insects is greater than in the larviciding operation. It should be emphasized, however, that the routine larvicidal application of aerosols or sprays results in adulticidal action on newly emerged adults and those resting in adjacent areas which are exposed to drift of the insecticide. Such a combination of larvicidal and adulticidal action has resulted in a significant reduction of adult mosquitoes in large-scale treatments.

The equipment used for airplane adulticidal treatment is identical with that previously described for larviciding. In general, the aerosol-type application has given the most satisfactory results because an immediate knock-down is secured, but good control has been obtained with coarse sprays which kill by means of the residual deposit left on foliage. This residual deposit, however, is considerably toxic to other forms of insect life. The dosage necessary to secure adequate adult control varies from 0.25 to 0.50 pound of DDT per acre, depending upon the density of woody cover being treated. The success of the aerosol operation at these low dosages is apparently partially dependent upon the irritant qualities of the insecticide which causes the mosquitoes to leave their resting places and to fly about in the insecticide cloud, thereby picking up a lethal dose. It has been shown that the percentage kill obtained is a function of the concentration of insecticide and the time of exposure to it. Therefore, the application should be made at dawn when meteorological conditions are most suitable and anophelines are most active.

Ground equipment, such as the jeep exhaust generator or the various types of smoke-aerosol generators, is capable of achieving the same results on a limited scale. This type of adulticiding is

ideally suited for the protection of outdoor gatherings especially in the evenings when mosquitoes are biting severely.

MIXING TECHNIQUES AND EQUIPMENT

Dust

It is not practical to mix large amounts of larvicidal dusts in makeshift equipment such as home-made drums and concrete mixers. In addition to the health hazard involved as a result of wasting of materials into surrounding air, the loss of ingredients costing $0.25 to $0.50 per pound is considerable. Several types of commercial mixing machines (fig. 104) may be converted for larvicidal dust mixing purposes. A good mixing plant should possess the following qualities:

1. Sufficient batch capacity (500 pounds).
2. Minimum mixing time (10 min.).
3. Opening of charging hopper sufficiently large to accommodate ingredient containers.
4. Dual sacking and weighing attachment.
5. Dust-tight system with special exhausting hoods for openings at charging and sacking locations.

On large mosquito control operations, a central mixing plant to supply the mixed dust for the entire operation will usually be the most suitable. Thus shipments of materials received in carload

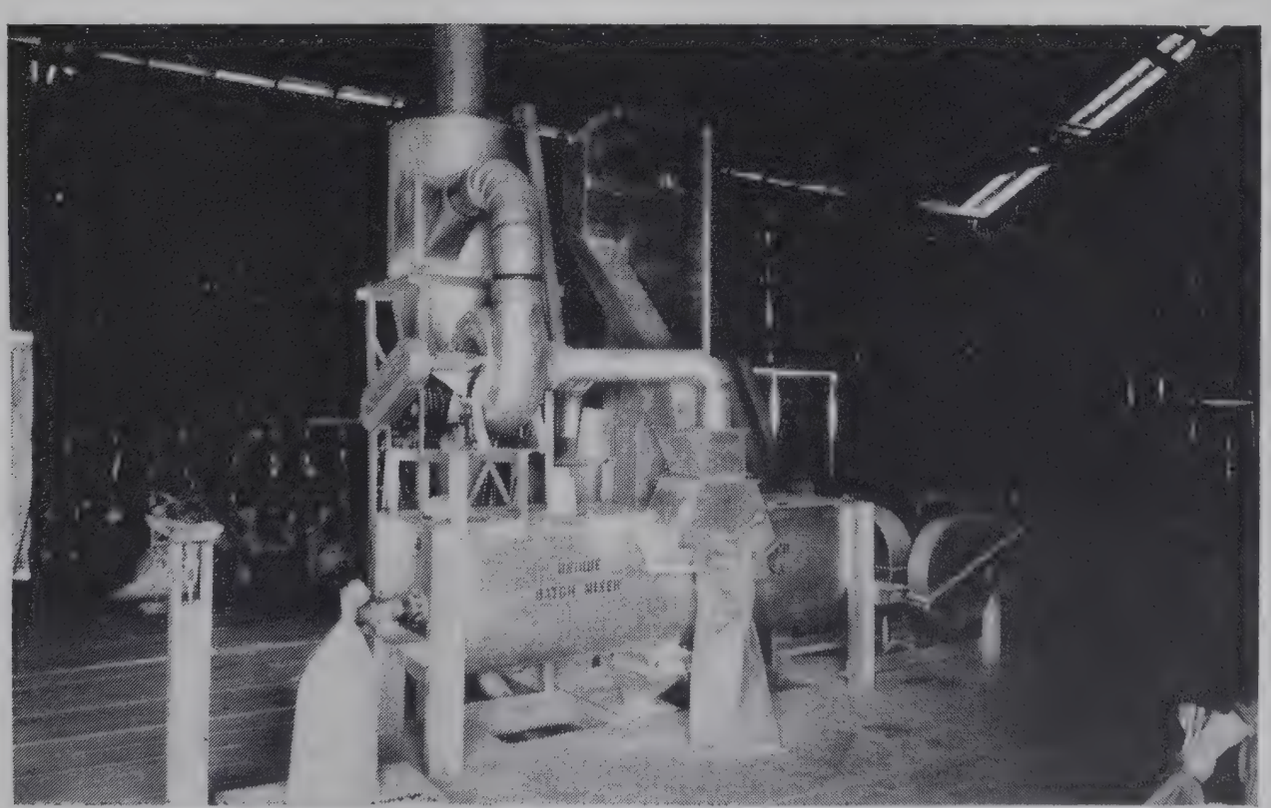


FIGURE 104.—Mechanical mixing equipment for larvicidal dusts.

lots may be mixed, bagged, and tagged. As the physical characteristics of materials supplied by different manufacturers vary, the shipments should be kept separate.

The mixed dusts are best sacked in amounts of 50 pounds. A three-ply waterproof paper bag is desirable and can be reused a number of times.

Every sack of mixed dust should be tagged giving the necessary information for field operations. The weights per cubic foot for all ingredients in dust mixtures should be determined by pouring the materials into a measure without additional packing so as to approximate the density of dusts in the equipment hopper. This information is required to determine the weight of active larvicides per cubic foot of mixed dust, and is used by the field forces for obtaining the proper valve opening for airplane dusting equipment. The weight of larvicide per cubic foot of mixed dust may be computed as follows:

$$W = \frac{1}{\frac{L}{W_L} + \frac{D}{W_D}} \times L$$

Where W = Weight of active larvicide in pounds per cubic foot of mixed dust
L = Percent of larvicide by weight
D = Percent of diluent by weight
W_L = Weight of larvicide in pounds per cubic foot
W_D = Weight of diluent in pounds per cubic foot

Solutions

Where a black oil marker is to be added to fuel oil or kerosene larvicides, the process of mixing and storage is complicated by the large volumes to be handled. Oils received by railroad or motor tank cars must be unloaded into a receiving tank or battery of tanks of sufficient capacity for mixing with the black oil. Agitation of the materials may be accomplished by releasing compressed air from lines in the bottom of the tank. On one large impounded water project, kerosene and black-oil shipments are received into a steel barge having a capacity of 50,000 gallons. By a piping and pump system the oils are mixed through recirculation while in transit to the reservoir storage tank locations.

The volume of materials to be handled in DDT larvicidal mixtures is much smaller than in the case of kerosene-black oil mixtures. Facilities for handling and mixing need not be extensive, and this permits the decentralization of mixing points. Both solvents and DDT are shipped in metal drums. A simple plant made of open

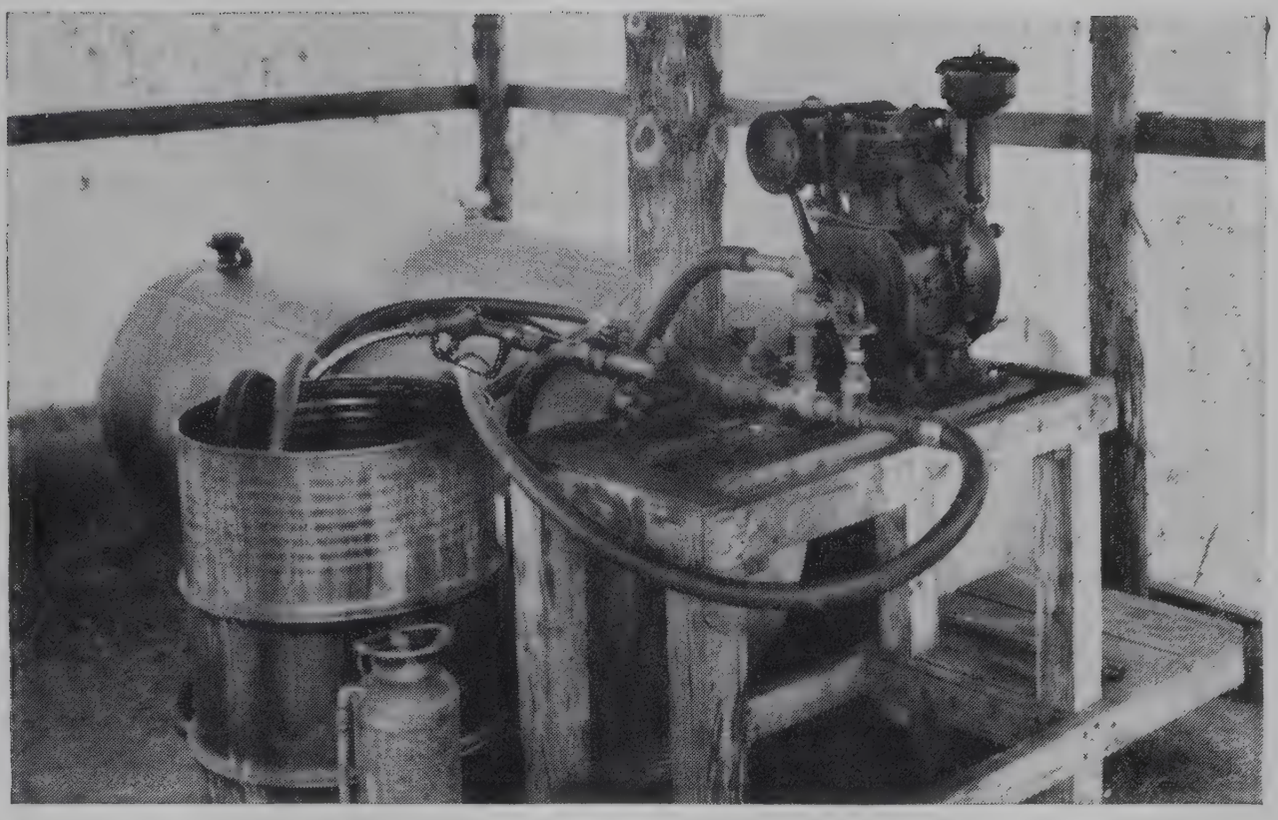


FIGURE 105.—Mechanical mixing equipment for DDT-oil solutions.

drums piped to a self-priming 5-horsepower pumping unit, which recirculates the solutions until mixed with a through-valve and hose arrangement, may be used to load storage drums with the larvicidal solution. It appears that transporting the larvicide in 55-gallon drums is more practical than bulk storage. Figure 105 shows a mixing plant for DDT-oil solutions located on an airplane loading field where materials are mixed and pumped into the airplane equipment as needed.

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VIII. MOSQUITO-PROOFING

GENERAL

Principles and effectiveness of mosquito-proofing

Even though woven-wire insect screens have been available since the discovery that mosquitoes transmit malaria, mosquito-proofing was not used in malaria control to any considerable extent until its effectiveness for the prevention of malaria was demonstrated during the sanitation of the Panama Canal Zone. During the 20 years succeeding 1910, the United States Public Health Service and other agencies demonstrated that mosquito-proofing of rural homes was a practical and effective method for preventing malaria transmission. Perhaps the largest of these demonstrations, and certainly one of the best documented, was that initiated in Lake County, Tenn., by the Tennessee Department of Public Health and the American Red Cross in the late 1920's. This program was done on a county-wide basis, and, while no provision was made for maintenance, statistical studies showed that the measure resulted in significant lowering of malaria transmission rates in protected families as compared with rates for unprotected families in an adjacent county.

The basic principle of mosquito-proofing lies in the fact that potent malaria vectors enter houses readily in an effort to satisfy an instinct for the repeated taking of human blood meals. The tendency of rural families in this country to congregate in or near their homes in the evening, when anophelines are most active, naturally suggests the raising of a barrier between mosquitoes and the human blood they seek. Mosquito-proofing does this effectively, serving to prevent not only the inoculation of humans by infected mosquitoes but also the inoculation of mosquitoes from infected humans. It thus tends to break in two places the epidemiological chain of circumstances which is responsible for malaria transmission.

While the effectiveness of mosquito-proofing can be measured in terms of household anophelism, its best expression is in terms of malaria prevention. Figure 106 is a histogram which shows malaria rates in population groups in the Tennessee Valley which have been protected by mosquito-proofing since 1938, and rates in population groups not so protected. It may be noted that there was a consistent reduction in malaria rates following the institution of mosquito-proofing; also, that the prevalence of malaria declined in unprotected population groups at the same time. The latter is believed

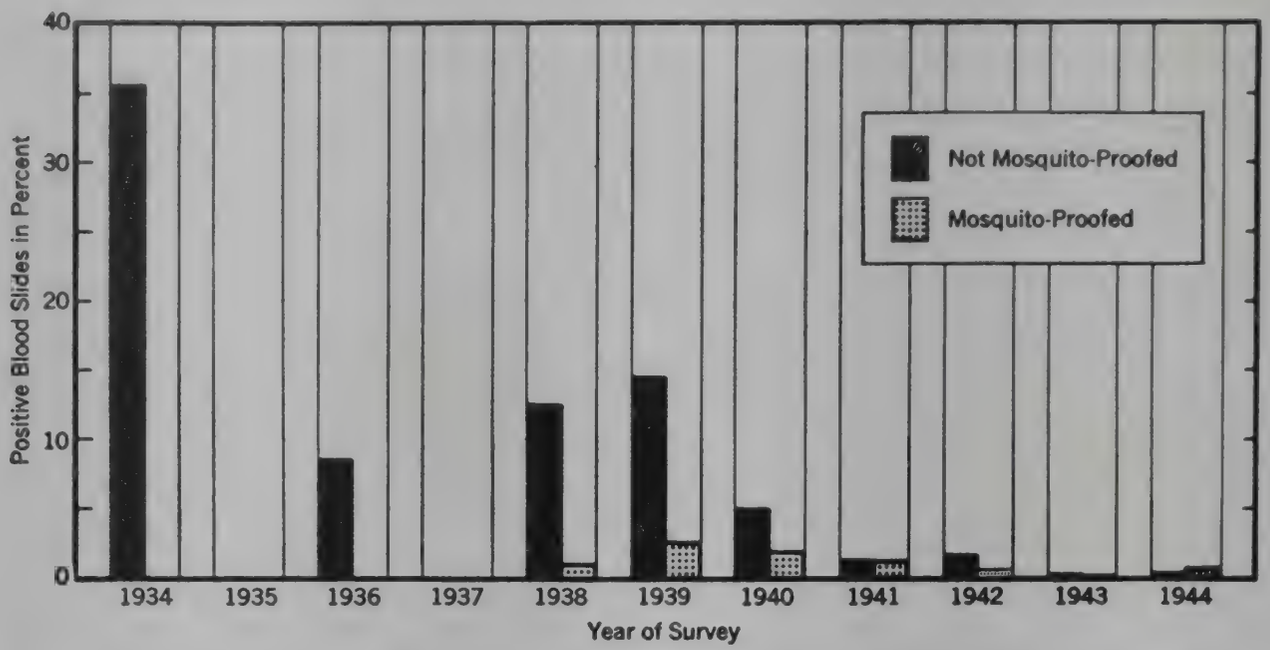

FIGURE 106.—Comparison of parasitemia rates on Wheeler Reservoir for houses mosquito-proofed with those not mosquito-proofed.

to be an expression of the downward trend in malaria prevalence which has been noted throughout the southeastern United States since 1935; or it could be a reflection of the decline in prevalence in the protected population groups, since the protected and unprotected populations were in fairly close geographical proximity. It should be pointed out that both the protected and unprotected populations lived in areas with very high *Anopheles* densities during the 10-year period shown.

Application in a malaria control program

Aside from its efficiency as a malaria control measure there are a number of factors to be weighed in considering the use of mosquito-proofing. Its use is usually limited to situations where adequate mosquito control cannot be obtained at a reasonable cost and a supplementary control measure is needed. Such situations would usually be of a temporary nature but in some instances might continue indefinitely. In some situations where the use of all available antilarval measures results in inadequate mosquito control, mosquito-proofing might be substituted for antilarval measures. In general, the cost of mosquito-proofing would rule out its use in concentrated areas of population such as in towns adjacent to impounded water. Whereas the costs of antilarval measures vary with the size of the mosquito-breeding area, the cost of mosquito-proofing varies with the density of the population. Thus, mosquito-proofing is most applicable in sparsely settled rural areas adjacent to relatively large mosquito-breeding areas.

The general state of housing is often the important determining factor. Effective mosquito-proofing consists of the complete closure

FIGURE 107.—Typical mosquito-proofed rural house in the Tennessee River Valley.

of all possible means of ingress for mosquitoes, not just the closure of doors and windows by screens. However, most houses can be made mosquito-proof with the supplemental use of wallpaper and a floor covering of roofing paper. Mosquito-proofing should include the screening of porches since occupants frequently occupy the porch in the early evening before retiring. In population groups where housing is uniformly poor, in the sense that extensive repairs have to be made to accomplish mosquito-proofing, the measure may prove to be impractical, at least on a permanent basis. Figure 107 shows a rural house typical of the type mosquito-proofed in the Tennessee River Valley.

In planning the application of mosquito-proofing a decision must be taken as to whether the measure is to be used on a temporary or on a permanent basis. It sometimes happens that it is necessary to impound reservoirs under conditions which will almost certainly result in prolific propagation of mosquitoes for one or two seasons, but where the ultimate expectation is that shore-line improvement or other physical changes will reduce or eliminate the hazard of anophelism. Such situations have occurred in Kentucky and Wheeler Reservoir areas in the Tennessee Valley and on some of the impounded water projects of the Alabama Power Co. In these instances mosquito-proofing was applied as a temporary measure to meet an emergency situation, and no effort was made to maintain it.

However, the permanent use of mosquito-proofing with continuing maintenance of the original work might have a proper place in an impounded water malaria control program under certain conditions. By way of illustration, one of these might be a situation where

mosquito-proofing would be actually needed to supplement the normal antilarval measures in preventing malaria transmission. In other situations it might be anticipated that mosquito-proofing could be substituted for one or more of the antilarval measures at a decrease in cost or an increase in effectiveness in malaria prevention, or both. In any event, local conditions, policies, and regulations would have to be taken into account in reaching a decision.

Insecticidal house-spraying, discussed in chapter IX, unquestionably enhances the effectiveness of mosquito-proofing.

Zone of application

The extent of the application of mosquito-proofing in terms of distance from mosquito-breeding places can theoretically be decided on the basis of the knowledge of the flight range of the vector. The maximum effective flight range of *A. quadrimaculatus* is usually not over 1 mile and the most intense anophelism and evidence of malaria transmission generally occur within one-half mile of impounded water breeding places. However, the dispersion of mosquitoes up to 1 mile, particularly under conditions of excessive production and scarcity of blood meals, usually warrants the application of mosquito-proofing for a mile from *A. quadrimaculatus* breeding places.

ADMINISTRATION OF MOSQUITO-PROOFING

In applying mosquito-proofing, whether by contract or force account, the owner of the impounded water project should arrange with the proper local health agency to complete the necessary negotiations with the home owners and occupants and approve the quality of the work. It may be advisable in this connection to do some educational work in acquainting the people with the purpose of the work. To be most effective mosquito-proofing should be applied on an area basis, and financed by the impounded water owners according to plans developed in cooperation with the local health agency.

Regardless of the administrative organization concerned with the planning, coordination, and technical supervision of mosquito-proofing construction and maintenance, the first step is to prepare adequate maps of areas where mosquito-proofing is to be done. These maps should be to a scale of about 1 inch equals 2,000 feet and should show accurately the location of all structures and important landmarks in the area. All houses should be numbered on the map, and a corresponding number should be affixed to the houses in the field. Numbers may be applied by nailing on metal numerals

or by stenciling. They should be of a size and location which can readily be seen from the road. The maps should be kept up to date, i.e., deleting houses which have been destroyed and adding houses which are built. This work can be done conveniently during maintenance operations or malaria surveys.

Preliminary to construction work an accurate survey of each house should be made in order to estimate the amount of materials. A survey sheet such as that in figure 108 showing the floor plan, the number and size of apertures to be closed, and the various materials required for mosquito-proofing is a convenient method of recording these data for bills of materials or shop orders and

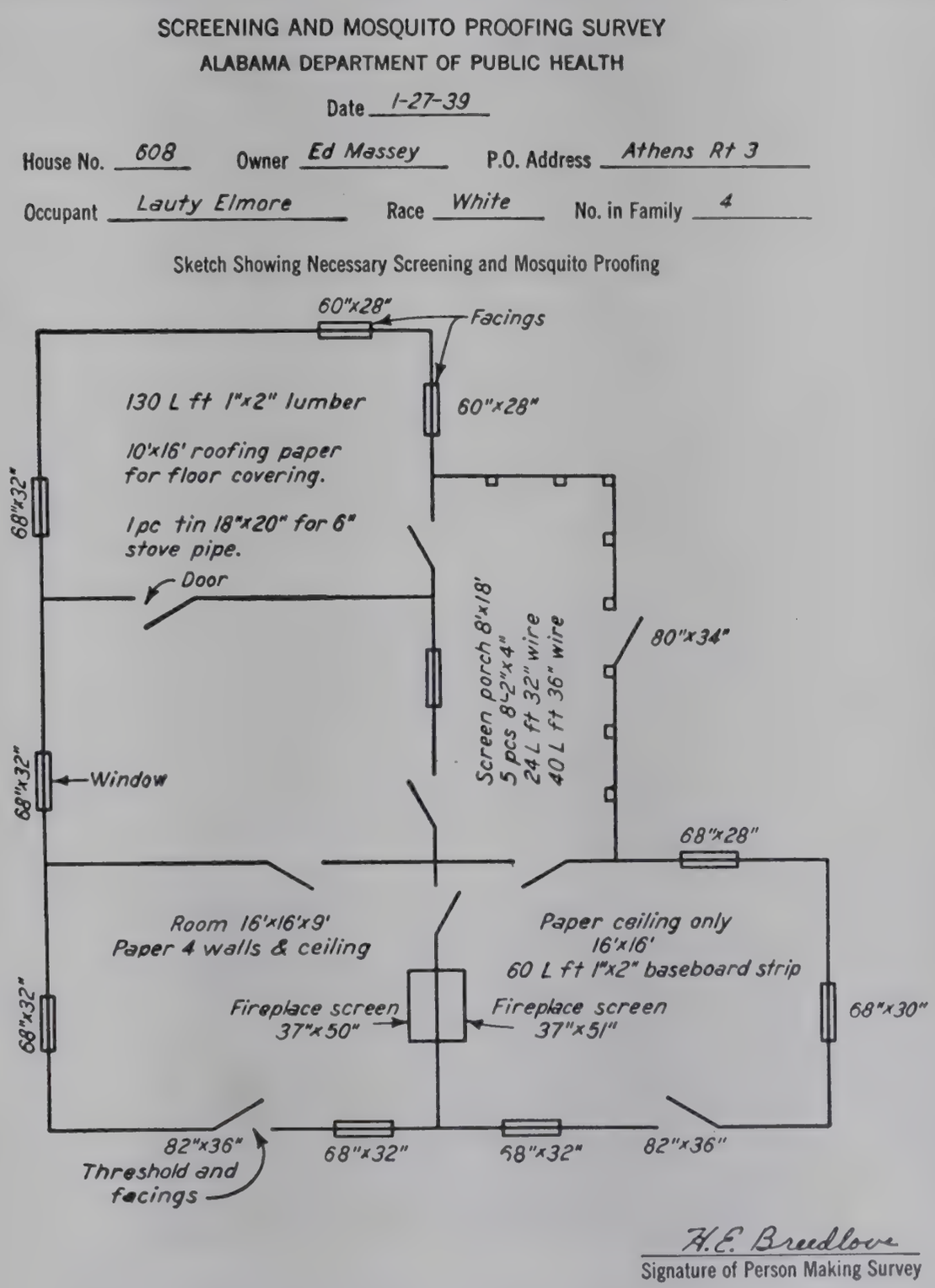

FIGURE 108.—Typical survey form for house mosquito-proofing.

for a reference file. When a mosquito-proofing program of a large area has to be done expeditiously, preliminary estimates for the purchase of materials can be made satisfactorily from a random sample survey of approximately 10 percent of the houses to be mosquito-proofed. This method was followed preliminary to mosquito-proofing approximately 1,200 houses in Kentucky Reser-

FIGURE 109.—U. S. Public Health Service screen door as modified by the Tennessee Valley Authority.

voir area in 1944-45; the estimates obtained were remarkably accurate. Eventually, however, a survey of every house should be made before construction work is begun.

MOSQUITO-PROOFING CONSTRUCTION

Prefabrication, screen door design, and materials

In the interest of efficiency and uniform construction screen doors and fireplace screens should be made in a shop or at some central point where special construction facilities are available. The sizes of the doors and screens can be obtained from the survey sheets of the individual houses.

From the standpoint of simplicity of construction and long life, the so-called Public Health Service door, devised by Coogle in Mississippi nearly 20 years ago, can scarcely be improved upon. Construction details of this door as modified by the Tennessee Valley Authority are shown in figures 109 and 110. Because of shortages in critical materials during the war a somewhat different door frame was used for the Kentucky Reservoir mosquito-proofing work. This door is shown in figures 111 and 112. The details of this frame are

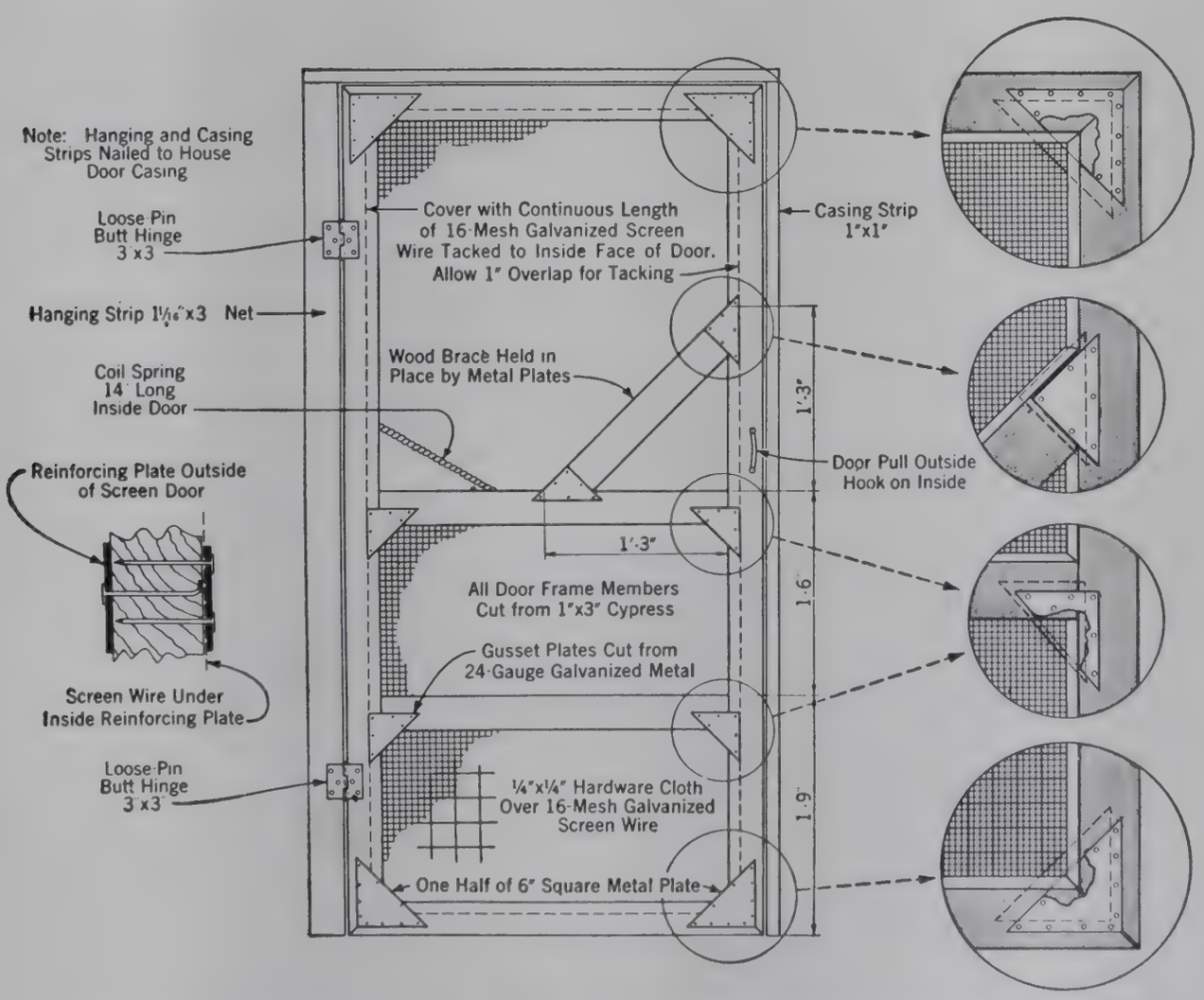
Note: Hanging and Casing Strips Nailed to House Door Casing
Loose-Pin Butt Hinge 3"x3"
Hanging Strip 1 1/16"x3" Net
Coil Spring 14" Long Inside Door
Reinforcing Plate Outside of Screen Door
Screen Wire Under Inside Reinforcing Plate
Loose-Pin Butt Hinge 3"x3"
Cover with Continuous Length of 16-Mesh Galvanized Screen Wire Tacked to Inside Face of Door. Allow 1" Overlap for Tacking
Wood Brace Held in Place by Metal Plates
1'-3"
All Door Frame Members Cut from 1"x3" Cypress
Gusset Plates Cut from 24-Gauge Galvanized Metal
1/4"x1/4" Hardware Cloth Over 16-Mesh Galvanized Screen Wire
One Half of 6" Square Metal Plate
Casing Strip 1"x1"
Door Pull Outside Hook on Inside
1'-3"
1'-6"
1'-9"

FIGURE 110.—Diagram of U. S. Public Health Service screen door as modified by the Tennessee Valley Authority.

such as to require its manufacture in a well-equipped shop. Both designs have proved to be most satisfactory in use. While the materials required are shown in the drawings, emphasis is placed on the lumber which should be full 1 inch, preferably kiln dried, cypress stock. No other wood of comparable cost serves as well, particularly in exposed situations, without paint. Whenever possible, two coats

FIGURE 111.—Screen door designed to minimize the use of metal.

of outside paint should be applied to the frame before the wire cloth is applied in order to reduce warping and prolong the life of the frame.

Fireplace covers are most conveniently made from one-fourth to three-eighths-inch plywood or fiber board in a light frame of pine or cypress.

The wire cloth to be used for the doors and windows should be selected with care to prevent the entrance of mosquitoes and meet climatic requirements, and to give maximum permissible ventilation. In most instances in the Southeastern States these requirements can be met with a galvanized iron or steel wire screen with 16 meshes to the inch, woven of wires with a diameter of 0.011 inch prior to the zinc coating. (See appendix D for specifications.) When exposed to the corrosive action of gases or sea air, galvanized iron has a very short life and copper, bronze, or Monel metal wire cloth should be specified. In humid salt-air coastal regions where experience has shown that metallic screens last only 3 or 4 months, it may be desirable to use a nonmetallic or plastic screen. Where excessive vibration of screens is induced by strong winds, a wire heavier than the 0.011-inch diameter may be advisable. Sixteen-mesh wire with a diameter of the order of 0.01 inch gives an aperture width of 0.052 inch which is sufficient to keep out the North American vectors of malaria. It will not, however, always prevent the entrance of some of the smaller mosquitoes such as *Aedes aegypti* and will not, of course, prevent the entrance of sandflies. Where protection against the smaller biting insects has to be considered as well as mosquito-

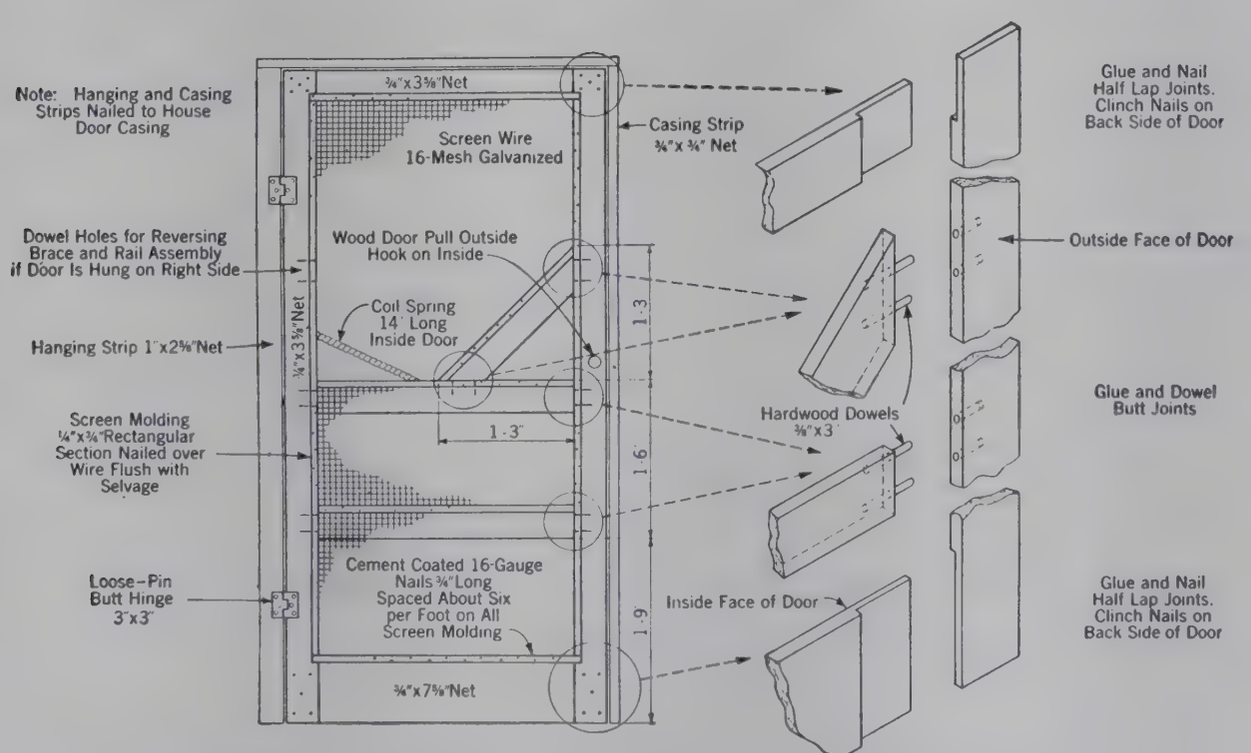
Note: Hanging and Casing Strips Nailed to House Door Casing
¾"x3⅜"Net
Screen Wire 16-Mesh Galvanized
Casing Strip ¾"x¾" Net
Glue and Nail Half Lap Joints. Clinch Nails on Back Side of Door
Dowel Holes for Reversing Brace and Rail Assembly if Door Is Hung on Right Side
Wood Door Pull Outside Hook on Inside
Outside Face of Door
Coil Spring 14" Long Inside Door
Hanging Strip 1"x2⅜"Net
¾"x3⅜"Net
1-3
Hardwood Dowels ⅜"x3"
Glue and Dowel Butt Joints
Screen Molding ¼"x¾"Rectangular Section Nailed over Wire Flush with Selvage
1-3"
1-6
Cement Coated 16-Gauge Nails ¾"Long Spaced About Six per Foot on All Screen Molding
Loose-Pin Butt Hinge 3"x3"
Inside Face of Door
Glue and Nail Half Lap Joints. Clinch Nails on Back Side of Door
1-9
¾"x7⅝"Net

FIGURE 112.—Diagram of screen door designed to minimize the use of metal.

proofing for malaria control, a finer mesh wire has to be used. Figure 113 shows the relationships between wire diameter, mesh, screen aperture, and percent of open area for any given screen.

Miscellaneous materials that are necessary for mosquito-proofing include lumber for repairs, 80- to 90-pound basic kraft paper for walls and ceiling, 45-pound asphalt roofing paper as floor covering, 28-gauge sheet metal for covering small holes, coil springs for screen doors, and miscellaneous hardware, nails, and tacks. An idea of construction and maintenance materials may be obtained from tabular statements of cost data in tables 27 and 28.

TABLE 27.—*Average quantities of materials and costs for mosquito-proofing one house.*

[Two Areas—Kentucky and Guntersville Reservoirs]

Item	Unit	Kentucky Reservoir		Guntersville Reservoir	
		1,032 houses[1]		192 houses[2]	
		Amount used	Total cost	Amount used	Total cost
Wire cloth, 16-mesh, windows, doors, and porches	Square foot	186	$ 4.37	169.14	$ 4.23
Wire cloth, 4-mesh, (kick panels)	do	—[3]	—	18.75	.78
Paper, 80-pound, basic kraft	do	483	.82	1442	2.42
Paper, 45-pound, roofing, floors	do	137	1.37	382	4.28
Door buttons	Each	—	—	6	.03
Door pulls	do	—	—	4.1	.05
Door springs, spiral	do	4.5	.15	3.9	.21
Gate hook and eye	do	—	—	5.2	.04
Sheet metal, 28-gage	Square foot	—	—	12.4	[4] .25
Tacks	Pound	1.8	.25	7.66	.91
Nails, assorted	do	5.3	.22	7.6	.32
Staple, (5,000 per box)	Box	.03	.05	—	—
Wood screws	Dozen	—	—	6.37	.15
Corrugated fasteners	do	—	—	[5]27.8	.23
Lumber, dressed pine	Board foot	100	7.09	201.34	15.05
Composition wall board	Square foot	12.3	.51	80.5	[4]1.61
Moulding for screens	Lineal foot	294	3.06	—	—
Door hinges, loose pinned butt	Each	7.5	.37	8.3	.81
Glue	Pound	.121	.04	—	—
Felt stripping (for filling cracks)	Lineal foot	—	—	13.1	.07
Miscellaneous		—	.96	—	.01
Cost materials		—	19.26	—	31.45
Labor[6]	Man-hour	47	56.40	106	62.54
Truck transportation	Mile	39.8	3.66	56.8	4.99
Total cost	—	—	$79.32	—	$98.98
Average number per house:					
Screen doors	—	3.3	—	3.5	—
Fireplace panels	—	.65	—	1.3	—
Screen porches	—	.12	—	.04	—
Screen windows	—	7.0	—	3.7	—

[1] Housing good.

[2] Housing poor.

[3] Hardware cloth not available and a wide bottom panel used. (See fig. 113.)

[4] Salvage.

[5] Public Health Service door requiring mitered corner joints held by fasteners.

[6] Skilled labor at an average rate of $1.20 per hour used in Kentucky Reservoir; unskilled labor at $0.59 per hour in Guntersville Reservoir. Of total man-hours, door construction required, 5.5 per house in Kentucky Reservoir, 13.0 per house in Guntersville Reservoir.

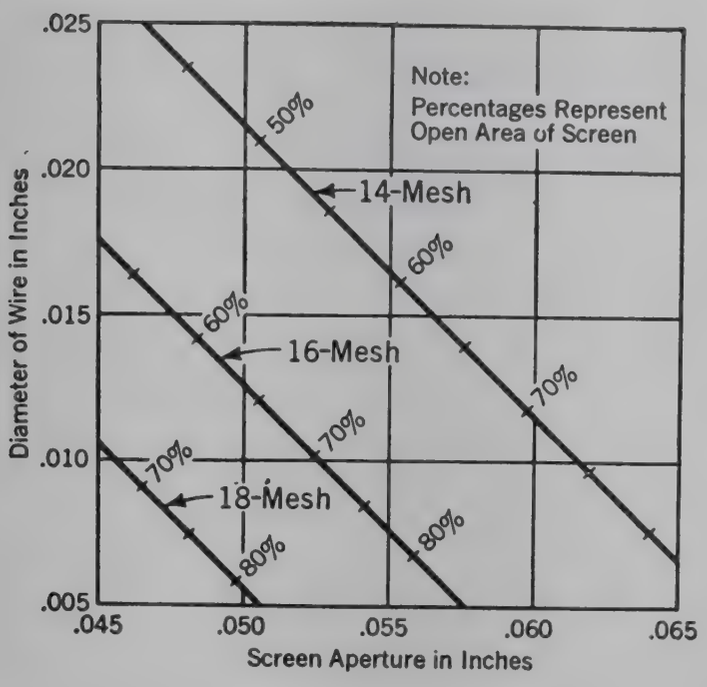

FIGURE 113.—Characteristics of 14-, 16-, and 18-mesh screen wire.

TABLE 28.—*Average quantities of materials and costs per year for mosquito-proofing maintenance for one house.*

[Averages from 643 Houses Repaired in 1944—Wheeler Reservoir, Alabama]

Item	Unit	Unit cost	Amount used	Total cost
Wire cloth, 16-mesh, replacement and repair	Square foot	$0.026	15	$ 0.39
Wire cloth, 4-mesh, (kick panels)	do	.0485	.44	.02
Paper, 80-pound basic kraft	do	.002	99	.20
Paper, 45-pound roofing, for floors	do	.0139	30	.41
Door buttons	Each	.011	.6	.01
Door pulls	do	.016	.42	.01
Door springs, spiral	do	.06	1	.06
Screw eyes for door fasteners	do	.0022	2.72	.01
Sheet metal, 28-gage	Square foot	.18	1	.18
Tacks	Pound	.15	2.16	.22
Lumber, dressed pine	Board foot	.05	6.5	.32
Fireplace screens, complete	Each	2.00	.09	.18
Screen doors, complete	do	4.00	.12	.48
Miscellaneous items		—	—	.07
Cost of materials		—	—	2.56
Labor	Man-hour	.719	12.40	8.92
Truck transportation	Mile	.125	7.29	.91
Total cost of maintenance				$12.39

MOSQUITO-PROOFING OPERATIONS

Installation of doors and fireplace covers

As a general proposition, no attempt should be made to use screen doors already in place, nor to fit screen doors inside of door frames. It will be found that most door frames are not square, and that hanging doors inside existing frames will necessitate costly individual fitting. Moreover, as most screen doors tend to sag to some extent, causing binding, refitting and maintenance operations will

be facilitated by installing the door as described below, instead of by the conventional method.

Preliminary to hanging screen doors, the facing of the door frame, particularly the threshold, should be repaired by appropriate carpentry. The door should then be hung to face against the outside of the door casing, overlapping the inside edges about 1 inch. This may be most easily done by first attaching the door to a hanging strip with hinges. The strip should be exactly the same length as the door, about 3 inches wide, and approximately 1/16 inch thicker than the door to prevent binding. The door is then hung in place by nailing the hanging strip to the door facing. A casing strip of the same thickness as the door material is then nailed to the door facing around the door, with just enough clearance to permit the door to open easily. Coil springs and other hardware are then applied to the door.

Screen doors should always open outward. While one stout spring is usually sufficient to insure tight closure of the door, it is sometimes necessary to have a spring at both the top and the bottom; occasionally, because of warpage, it may be necessary to change the position of the spring to assure a tight closure. If the design will permit, doors should be hung so that the screening material is on the inside; otherwise, children will try to ride on the door by standing on the upper edge of the bottom member.

As a considerable number of mosquitoes may enter a house through the chimney, it is necessary that all fireplaces be closed. Older methods of plugging the chimney from below or above, covering the top with a shutter or screen, or hanging moth balls in the fireplace or at the top have all proved to be unsatisfactory. Since fireplaces are frequently used during the summer for heating flat irons, a tightly fitting, removable panel offers the best solution for closing a fireplace. Such a panel can be made from plywood or composition board nailed to a light frame. It may be fitted to the mantle piece inside a facing strip, such as is used for the screen door, and fixed with turn buttons so that it can be removed at will. (See fig. 114.) A tight fit can usually be obtained except at the bottom where the hearth is often uneven. An attempt to correct the irregularity in the hearth by grouting with cement mortar will not solve the problem because the mortar eventually will disintegrate from the heat of fires. The best fit is obtained in most cases by scribing the contour of the hearth on the bottom of the panel frame and trimming it to fit.

Screening of windows

The first step in screening a window is to repair the facings in order to eliminate cracks through which mosquitoes might enter. As a general rule, window screens should be of full length and permanently attached to the facing of the window. As in the case of screen doors, no attempt should be made to utilize existing window screen frames unless they fit properly and are in good condition. In applying the wire screen it should be stretched as tightly as possible. This is particularly important, for vibration induced by wind may be sufficient to cause breakage of the wire where it leaves the window facing. The best screening practice is to use a width of wire which will overlap the window facing by at least 1 inch. The screen is fastened at the top of the window by a few tacks and the wire cloth stretched over the opening and held in place by additional tacks widely spaced. The screen is then fixed permanently in place by a soft wood molding strip secured with nails set every 2 inches. When the window sill protrudes beyond the facing, the best practice is to fill the angle formed by the sill and the facing with a triangular "furring block." The base of this block should extend so as to be flush with the edge of the window sill. The screen should be carried from the facing over this block and fixed beneath the sill with a molding strip. This technique is much better than the old practice of doubling the screen at the bottom of the window and fixing it to the upper surface of the sill by a double row of tacks, the doubled screen then being carried under the sill and fixed with another row of tacks. This practice resulted in tack heads cutting holes in the screen along the sill and often left a small opening at the angles formed by the sill and facing.

Covering and repairing floors, walls, and ceilings

It will be found in many instances that mosquito-proofing cannot be done without fairly extensive repairs of floors, walls, and ceilings. Floors frequently require bracing, and it is sometimes necessary to re-lay a floor. Small holes in the floors or in wooden walls can be closed by tacking patches of sheet metal over them. In houses which are not ceiled, cracks at the eaves must be closed. Such holes can be closed with various commercial calking compounds or lime-cement mortar.

Multiple cracks in the walls and ceilings may be closed by papering the room completely, using an 80- to 90-pound basic kraft paper. The edges of the paper should be lapped about 1 inch, and the paper fixed in place with large-headed bill-poster tacks. The joints can be reinforced with molding strips nailed over the lapped edges. This

paper is not unattractive and usually adds to the appearance and comfort of a room. Multiple cracks in floors may be covered with a cheap grade, smooth-finished asphalt roofing fixed in place with large-headed tacks driven through the lapped edges. Alternatively, the joints can be butted and cemented to the floor. This material is objectionable from the standpoint that it holds dirt, and in hot weather asphalt may adhere to bare feet; but any substitute such as cheap linoleum increases construction cost tremendously. Figure 114 shows use of these materials with a fireplace closed by a composition-board panel.

Porch screens

Whenever the cost is not prohibitive, at least one porch should be mosquito-proofed (fig. 115). This enables the people living in the house to have protection against mosquito biting without retiring to bedrooms. In many sections of the Southeastern States, houses of the "dog-trot" type are found, the "dog-trot" serving in effect as a porch since it is a space open on two sides separating the rooms of the house. Whenever possible, these open spaces should be closed by screens.

Mosquito-proofing expedients and adjuncts

It is frequently found that mosquito-proofing an entire house is practically impossible because of necessary expensive repairs. In

FIGURE 114.—Interior of a mosquito-proofed house showing wall papering, floor covering, and fireplace cover.

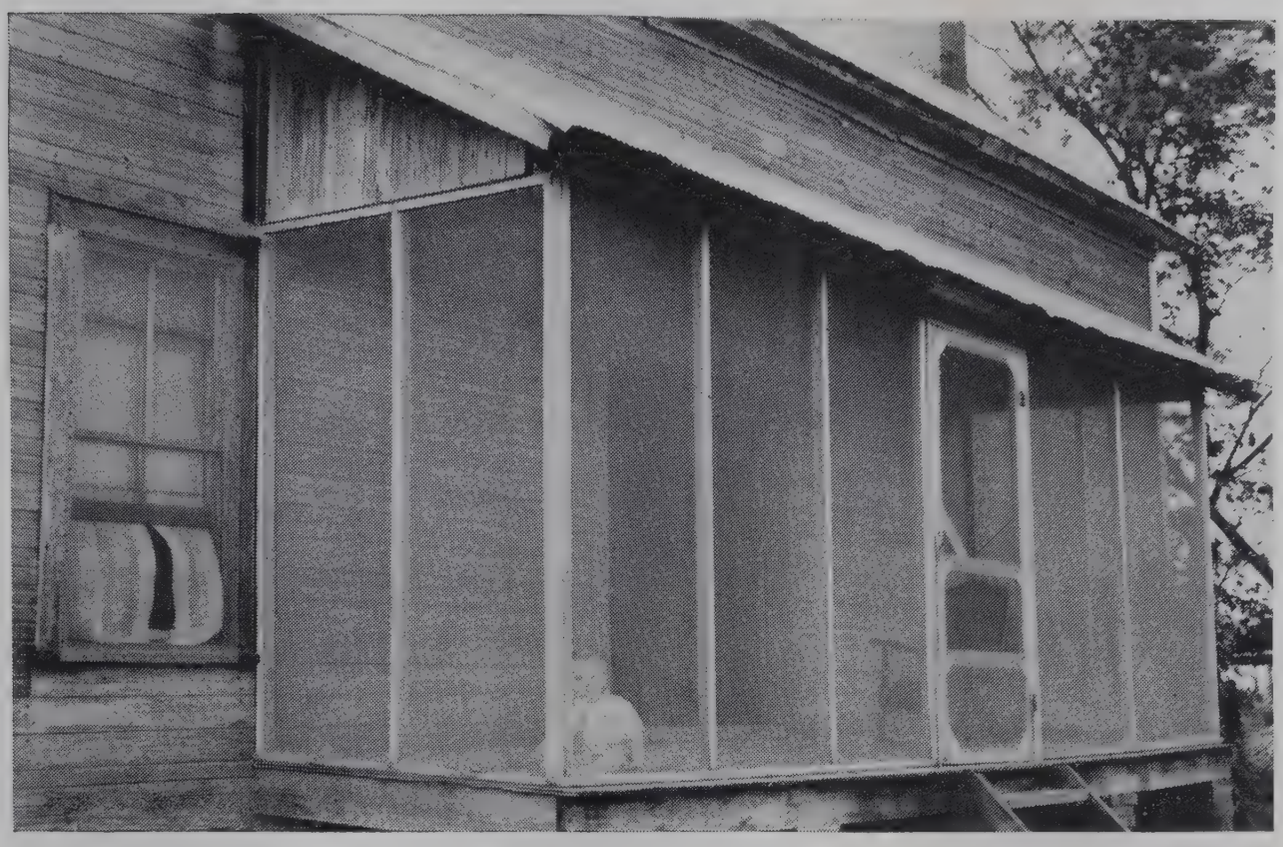

FIGURE 115.—Screened porch of a mosquito-proofed house in Wheeler Reservoir Area.

most cases, however, it will be found that one or more rooms can be mosquito-proofed. In this case, the order of preference should be sleeping rooms, rooms where meals are cooked or eaten, and other living rooms. Where only one or two rooms are to be mosquito-proofed, it is, of course, necessary to hang screen doors to interior door frames. This should be done according to principles previously discussed.

The effectiveness of a mosquito-proofing program may be increased by also including buildings other than houses that are likely to be occupied for any significant periods of time during the night.

The use of electric fans to keep air in motion in sleeping rooms or on screened porches, particularly in the vicinity of exterior doors, further minimizes the chance of mosquito biting, but is a device which is not likely to be used in most rural houses.

An educational program designed to instruct householders in the proper use and care of the mosquito-proofing should go hand in hand with mosquito-proofing programs. This might take the form of community demonstrations and talks, but should include solicitation and instruction in the homes. Placards on fireplace screens and doors calling attention to their proper use and care have been found to be useful.

Finally, the destruction of mosquitoes by swatting should be encouraged. The most valuable adjunct of all, residual sprays, is treated in a separate chapter.

COST OF MOSQUITO-PROOFING CONSTRUCTION AND MAINTENANCE

The condition of the housing and the price of labor are the principal determinants in the cost of mosquito-proofing as may be seen from tables 27 and 28. When housing is generally bad, this fact is reflected in the cost for materials for repair and for covering the walls, ceilings, and floors, and in the time required to mosquito-proof a house. As noted in table 27 poor houses may require material costing 35 percent more than for good houses.

Mosquito-proofing should be inspected annually and any necessary repairs made to keep it in good condition. With adequate maintenance mosquito-proofing of the type described will usually require replacement of all original construction in about 8 years. It has been noted that when mosquito-proofing has been applied to poor houses, it may outlast the house.

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IX. HOUSE-SPRAYING

INTRODUCTION

Prior to the discovery of the residual insecticidal value of DDT, conventional sprays were applied as a mist of small droplets which killed the insects upon contact. This type of spray usually gives temporary relief and when consistently applied is of value for the control of malaria. However, as commonly applied the effects are temporary and spraying during the day or in the evening will not give protection throughout the night. Recently improved equipment for the application of these air sprays such as the aerosol "bomb" have increased the effectiveness and ease of application, but sprays which produce more lasting results are desirable for malaria control.

With the advent of DDT it has been found possible to spray a solution of this insecticide on the walls and ceilings of a house and deposit a film or residue of DDT crystals on the treated surface. Malaria mosquitoes and other insects that come in contact with these crystals are poisoned and later die if they have had sufficient exposure. Sprays applied in this manner have been termed "residual" or "surface" sprays.

This method of killing insects is especially valuable in malaria control since mosquitoes which enter houses are those most likely to bite persons infected with malaria and thereby become potential vectors of the disease. In houses sprayed with DDT these infected mosquitoes will have ample opportunity to rest on a treated surface and be killed before they are able to transmit malaria to other people. This is the basic principle of malaria control through residual spraying.

The use of residual house-spraying as a malaria control measure is relatively new, and until further evidence of its effectiveness is obtained it should be considered as a supplementary or emergency measure to be used in conjunction with the other control methods previously discussed in this manual.

The need and value of DDT residual house-spraying for the control of malaria, or as a means for supplementing other measures, will be determined by local conditions, the extent and distribution of breeding areas, the density of the malaria vector, population density, the prevalence of malaria, the customs and housing conditions, and the success of other antimalaria measures. Sometimes residual spraying may be justified for the comfort it gives to the

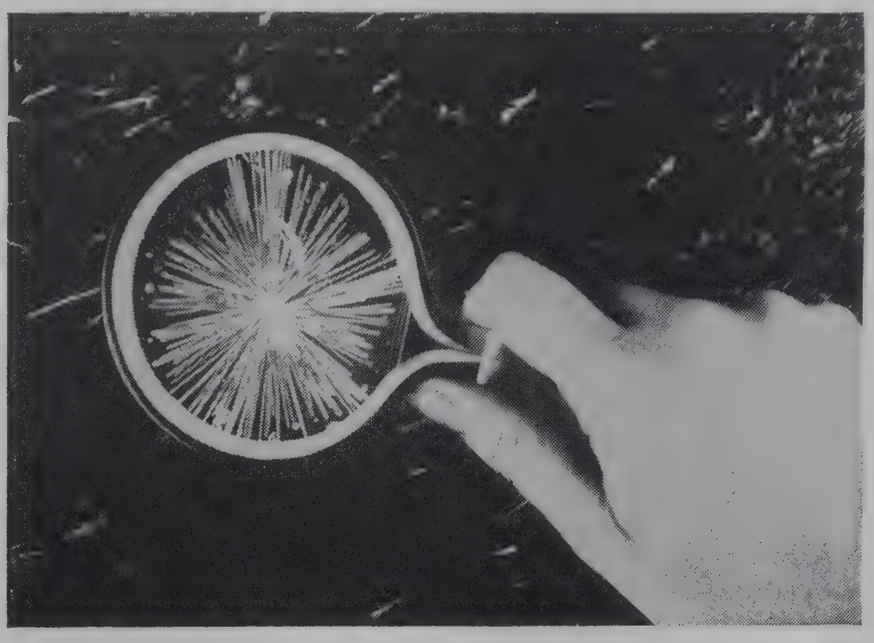

FIGURE 116.—DDT crystal highly magnified.

householder and for its value in the suppression of other insect-borne diseases. In the event of an outbreak of malaria, residual spraying would be recommended regardless of antilarval measures already in progress since it immediately kills the adult mosquitoes.

PRINCIPLES OF DDT RESIDUAL SPRAYING

A residual insecticidal spray is one which leaves a residue of the insecticide over the sprayed surface after the carrier or solvent has evaporated. To be most effective for the control of insects this residue should be uniformly distributed over the sprayed surface; it should adhere well and be relatively nonvolatile; it should kill on contact, and retain its lethal properties over long periods and it should not repel the insects which it is desired to kill. If it is to be used in dwellings, the residue or deposit should be inconspicuous, it should not be toxic to humans, and the insecticide and its carrier or solvent should not mark or mar surfaces, or possess a disagreeable lingering odor.

Dichloro Diphenyl Trichloroethane or DDT, as it is commonly called, possesses most of these characteristics. It is soluble in organic solvents such as fuel oil and xylene. By the addition of a suitable emulsifier these solutions can be emulsified in water to form a spray emulsion. When a solution or emulsion of DDT is sprayed on a surface as a fine wet mist, a deposit of DDT crystals is left on the sprayed surface when the solvent evaporates (fig. 116). These crystals adhere well to most surfaces, are relatively nonvolatile, and are toxic for 3 to 4 months to mosquitoes which come in contact with them for one-half to 2 hours. Such spray residues are relatively inconspicuous and are harmless to humans. Mosquitoes alight and rest on such treated surfaces as readily as they do on untreated surfaces. After the

mosquitoes have been in contact with the DDT deposits for a short time, however, they become irritated and a large portion of them fly toward the light. Generally *quadrimaculatus* mosquitoes receive a lethal dose before they are sufficiently stimulated to leave. Since most of those which are affected may escape before dying, the effectiveness of residual sprays should be judged by the absence of live mosquitoes rather than the presence of dead ones.

Because DDT is not a repellent and requires some time to act, it will not prevent mosquitoes from entering buildings and will not entirely eliminate biting. During the first 2 to 6 weeks after treatment when the deposit is fresh, the irritant effect is produced so quickly that a large percentage of mosquitoes leave before taking a blood meal and thus protection against biting is afforded.

PLANNING AND CONDUCTING A RESIDUAL SPRAY PROGRAM

Plans for the spraying program should be completed well in advance of the beginning of actual spray operations so that materials and equipment needed can be ordered and the necessary personnel secured. If a malaria control program is already being conducted on the reservoir, existing facilities and personnel may be used, at least in part, for residual spraying. The preliminary work essential for initiating the program the following summer should be conducted in the late fall and winter. Regular malaria control personnel can be transferred to this task at the end of the mosquito-breeding season. These men are already acquainted with the area, know many of the people, and are fitted for making the public contacts and securing the needed information.

Mapping the zone to be treated

After the area which is to be treated has been selected, suitable maps of the area showing all the houses and access roads should be secured. Such maps are necessary for the most efficient planning of each day's work and are of value to the crew in finding the houses. The best available map of the area should be converted to the desired scale (e.g. 1 inch equals 2,000 feet) and all houses plotted from actual surveys in the field. For ease of identification and keeping records, all houses should be numbered and the numbers shown on the map. Stenciled or metal numbers may be used on the houses. Estimates of the total area to be sprayed in each house should be made at the time the houses are numbered.

A knowledge of the number and location of the units to be treated and of the total area to be sprayed is essential for the planning of the

program and the carrying out of day-to-day operations of the crew. The total area to be sprayed will determine the amount of DDT and other materials needed.

Public relations

If spraying operations are not carried out by or in cooperation with the local health agency, arrangements should be made with them for their cooperation in making the public contacts which must precede the inauguration of the spraying operations.

A public meeting called by the local health agency in cooperation with the leading citizens is a preferred method for acquainting the people with the program. Notice of this meeting can be given to all people in the zone which is to be sprayed at the time the houses are numbered. At such meetings the purpose of the project, the method of spraying, desirability and benefits of the treatment, and its toxicity to animals other than insects can be explained. If the benefits of the DDT spraying and its action are properly presented, the people will cooperate and aid the program. Their cooperation is desirable in preparing their houses for spraying and replacing the furnishings after spraying, a task which requires considerably more time than the actual spraying operations.

In order to insure preparation of the houses for spraying, clear and concise instructions must be given as to just what should be done to prepare for the spray crew. The following should be stressed:

1. All furniture should be moved from the walls toward the center of the room to provide adequate space for the operator to spray the walls and ceiling.

2. All furniture with varnished or highly polished surfaces should be placed in the center of the room so that it can be covered with cloths to protect it from the spray. Dressers, highboys, sideboards, cupboards, and bookcases should be placed with their backs to the outside so these surfaces may be sprayed. The underside of tables and beds should also be sprayed.

3. Pictures and mirrors should be removed from the walls and placed face down on a suitable object, or on papers, so that their backs can be treated.

4. Exposed food, dishes, cooking utensils, and glassware should be removed from the house if practicable or carefully covered to protect them from the spray. They should not be placed on the back porch as it may be sprayed.

At the public meeting the area to be sprayed should be clearly defined and the reason explained for spraying in that area only.

PREPARATION OF THE SPRAY CONCENTRATE AND EMULSION

If a larvicidal program is in operation, or is to be put in operation, the headquarter facilities for such activities will probably be suitable for all mixing operations. Because DDT occupies much less space in solution than it does in powder form, and because it is easier to ship or carry the concentrate which contains all the ingredients than it is to transport them separately, it is advisable to prepare the concentrate at a central mixing station. As the concentrate can be prepared rapidly one mixing plant can supply all the concentrate needed for several areas or several reservoirs. Further, this procedure makes it possible to keep all supplies, repair parts, and equipment at one central point and to minimize the amount of equipment necessary. If DDT solutions or emulsions are being used for larviciding the same mixing equipment can be used for preparing the concentrates for both larviciding and residual spraying.

DDT

Chemically pure DDT is a dry, white, crystalline powder. The commercial product is usually composed of 70 to 75 percent para pará DDT, 15 to 20 percent ortho para DDT, and small amounts of several other compounds. (Para pará DDT is considerably more toxic than ortho para DDT). The relative amounts of the various constituents in the DDT, for sale by the several concerns now engaged in its manufacture, vary in accordance with the purity of the materials used, the conditions of preparation, and the extent of purification.

Although DDT is only very slightly soluble in water, it is soluble in oils and readily soluble in many other organic solvents. It may be used as a straight solution, as a water emulsion of DDT in an organic solvent, or as a suspension of crystalline DDT in water.

Solvents[3]

Factors of importance in the selection of a solvent are the relative solubility of DDT in the solvent, odor, inflammability, cost, availability, and spraying qualities. Solvents which have been used are xylene, kerosene, combined mono- and dimethyl naphthalenes, orthodichlorobenzene, pine oil, and sulphonated pine oil.

Pine oil and sulphonated pine oil have persistent strong odors which linger for several days and make them undesirable for house-spraying. Further, the residue produced by them is not as effective or durable as that secured from some of the other solvents, their ability to dissolve DDT is limited, they cannot be used to make

[3] Formulations and chemicals mentioned in this chapter are given in appendix C.

strong concentrations capable of great dilution to form emulsions, and they are more costly than some of the other solvents. Orthodichlorobenzene is difficult to emulsify and therefore requires large amounts of emulsifier. Further, emulsions with this solvent produce deposits which lose their toxicity much more rapidly than those produced with some other solvents. DDT emulsions made with either kerosene or the combined mono- and dimethyl naphthalene solvent give good residual toxicity. These solvents, however, have a pronounced odor which lingers for 1 to 2 days and makes them somewhat undesirable for house-spraying. The latter volatilize slowly, however, and deposits formed from them are not as noticeable as those formed from the more rapidly volatilizing solvents such as xylene. The methylated naphthalene solvents are satisfactory for dark or varnished surfaces. Kerosene gives a deposit having good residual toxicity but it has an odor which lingers for a day or two. For some surfaces which have a tendency to mark, it is superior to xylene. Its greatest drawback is its inability to dissolve large quantities of DDT; a concentrated solution contains only about 5 gm. of DDT for each 100 ml. of the solution. It must, therefore, be applied directly without dilution at the rate of 4 ml. per square foot of surface area to obtain a deposit of 200 mg. of DDT per square foot. This requires the transportation of large amounts of solution into the field which may be a disadvantage.

Solubility of DDT in various solvents in grams per 100 ml. of solution.

Solvent	DDT capacity (Gm. DDT/100 ml. solution)	Working capacity (Gm. DDT/100 ml. solution)
Xylene	43–48	35
Aromatic, paraffin and naphthene mixtures (Solvesso No. 2)	40–45	35
Mixtures of mono- and dimethyl naphthalenes (Velsicols, etc.)	40–50	35
O=dichlorobenzene	45–50	35
Sulphonated pine oil	21–26	15
Pine oil	14–15	10
Kerosene	9	5
Mineral spirits	9–10	5

Although xylene may mark some surfaces, such as varnish, or dark paint and enamel, it gives deposits with good residual toxicity. Further, it is volatile, does not produce lingering odors, is readily available at reasonable cost, and will dissolve large amounts of DDT. It can be used to make concentrates which may be diluted many times to make satisfactory emulsions. This greatly reduces the amount of material which must be transported, and a large area can be sprayed with a small amount of concentrate. When all factors and conditions are considered, xylene and kerosene are two of the better solvents.

Neither of these solvents creates a fire hazard at concentrations used for residual spraying.

Recently, wettable DDT powders have been placed on the market. These materials can be added directly to water to form suspensions of DDT. Such suspensions give effective residual coatings, but they leave a very noticeable deposit which is objectionable in well appointed houses. However, they have the advantage of being free of the fire and toxicity hazards of the xylene preparations.

Emulsifiers

Since most organic solvents are not readily miscible with water, it is necessary to add an emulsifying agent to secure a stable spray emulsion. A large number of emulsifiers are available and quite a number give satisfactory emulsions for spraying operations. Availability, ease of mixing, cost, and stability of the emulsion are the main determining factors in the selection of an emulsifier. A list of emulsifiers is given in appendix C.

Formulations

It is desirable to employ formulations which are simple, easy to mix, and concentrated so that a minimum amount of material need be taken to the job each day. All quantities should be expressed in units familiar to everyday usage, i.e., pounds, gallons, quarts, or ounces. The total solution capacity of the solvent for DDT should be utilized in order to minimize the amount of concentrate to be handled. For xylene the following basic concentrate formula is satisfactory for summer conditions or temperatures above 50° F; Xylene, 1 quart; DDT, 1 pound; and about 2 oz. of a suitable emulsifier. If larger quantities are desired, any multiple of this basic formula may be used. This concentrate contains about 35 percent DDT, or almost 350 grams of DDT per liter. When this concentrate is diluted 1 part to 6 parts of water, a 5-percent emulsion is formed which contains roughly 50 gm. of DDT per liter. When this emulsion is applied at the rate of 4 ml. per square foot, a residual dosage of 200 mg. of DDT per square foot is secured. As the solubility of DDT in xylene is influenced by temperature, mixing operations should be conducted at temperatures of 60° F, or above. The concentrate must never be stored where the temperature drops to 40° F. as the DDT crystallizes out at that temperature.

If kerosene is used as the solvent a 5-percent solution can be obtained by dissolving 21 pounds of DDT in 50 gallons of kerosene. This gives about 52 gallons of spray concentrate, each milliliter of which contains about 50 mg. of DDT.

Hand mixing

Where small amounts of spray concentrate are needed, a simple rocker-type hand mixer (fig. 117) is satisfactory. If a barrel and spigot are available this mixer can be constructed at the mixing plant. A large funnel should be provided for the introduction of the ingredients through the bunghole at the top of the mixer. To secure the largest amount of concentrate with fair rapidity of mixing, 28 to 30 gallons of concentrate should be prepared at each operation. The following quantities can be used for the concentrate: Xylene, 21 gallons; DDT, 84 pounds; and about 5 quarts of a suitable emulsifier. Dilution of this concentrate with 6 parts water to 1 part concentrate will give a 5-percent emulsion.

Power mixing

When large amounts of concentrate are required the power mixer shown in figure 118 is satisfactory. (See appendix D.) For this mixer a suitable formula for the concentrate is as follows: Xylene, 31.5 gallons; DDT, 125 pounds; and about 2 gallons of a suitable emulsifier. These ingredients make a little over 43 gallons of the residual spray concentrate. With proper manipulation of the mixer, fluids can be circulated through the pump and tank, introduced into the mixer, and removed from it without any actual personal contact with the chemicals. A complete mixing operation requires about 15 minutes or less depending on temperature. DDT goes into solution very slowly at temperatures below 60°F., and it is advisable to carry on mixing operations on warm days when the temperature is well above 60°F.

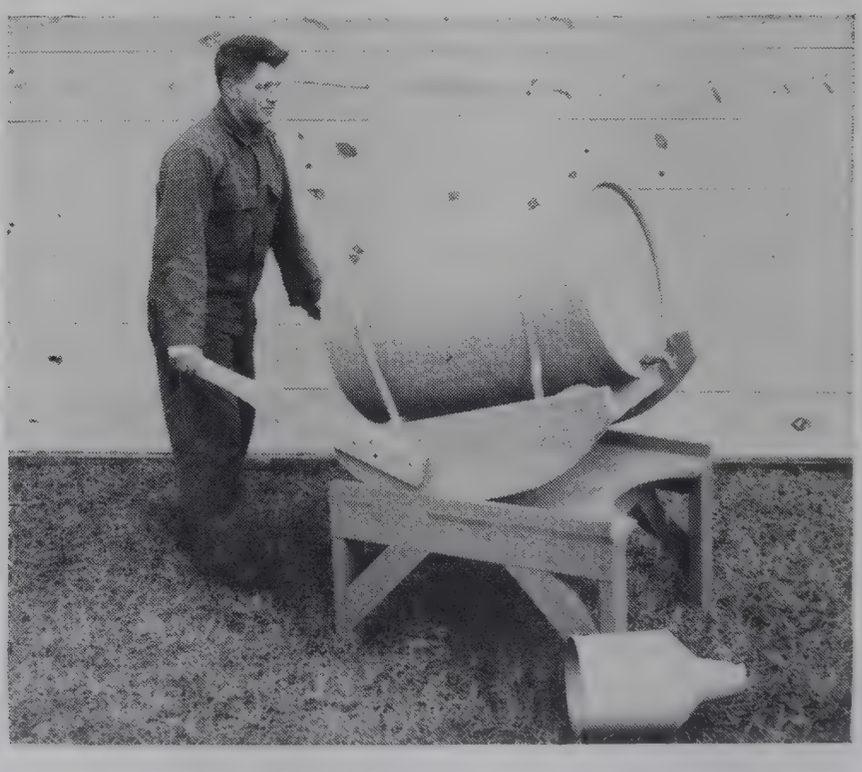

FIGURE 117.—Rocker mixer.

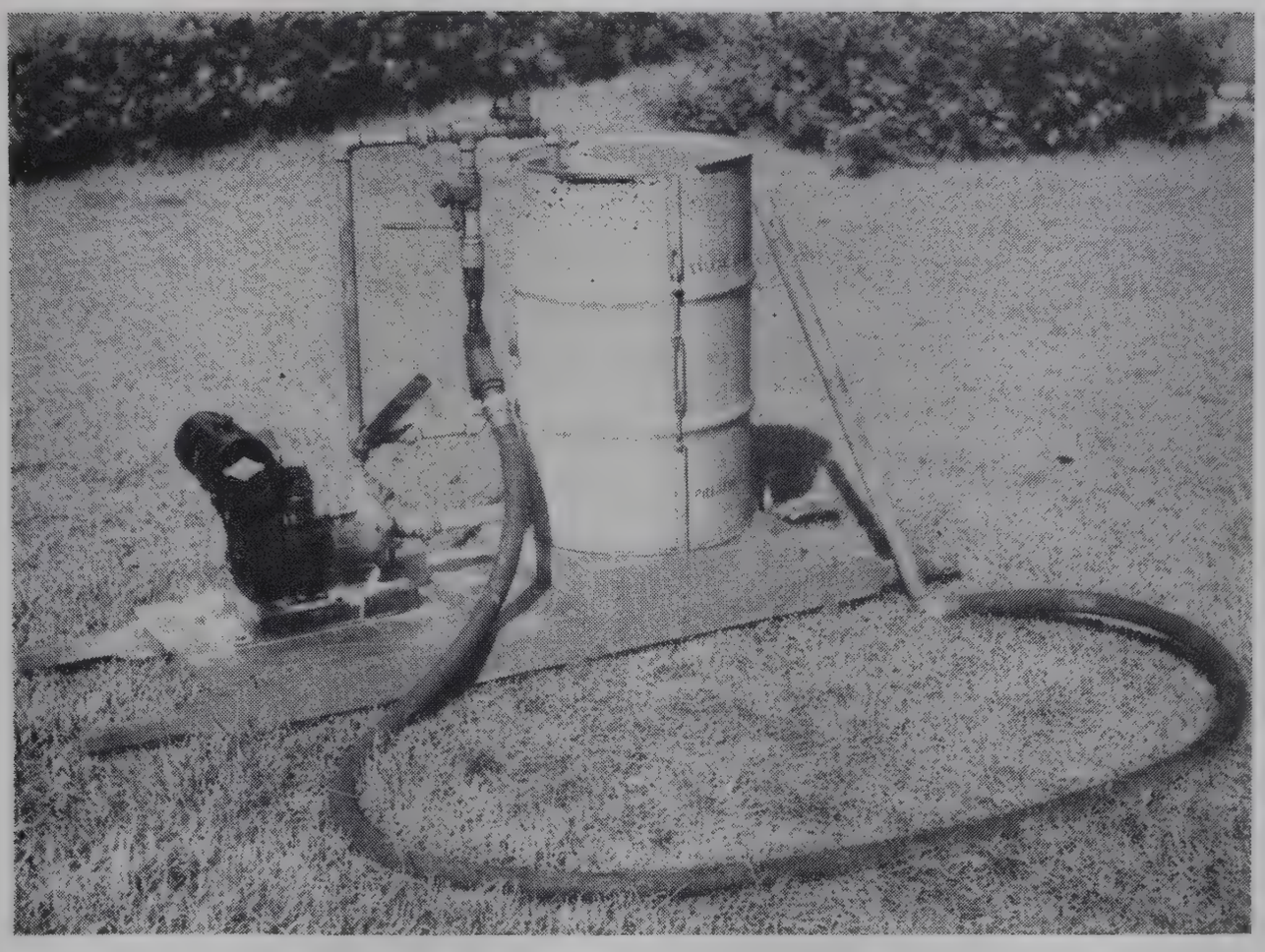

FIGURE 118.—Venturi power mixer.

APPLICATION OF RESIDUAL SPRAYS

To be poisoned by DDT an insect must actually come in contact with the material. Fundamentally, therefore, the effectiveness of DDT residue depends on the density and distribution of the particles of DDT on the surface. This, in turn, depends on the solvent, the amount of material applied, the method of application, and the character of the surface being sprayed. Thus, all these factors must be considered in residual spraying and special care taken to insure proper application of the spray. Several types of sprayers are available, and hand- or power-operated equipment may be used. In general, hand-operated equipment is the most suitable in rural areas where the houses are scattered and difficult of access whereas power equipment is the most suitable in urban areas where the houses are close together and near the street.

Spraying equipment

Hand sprayers—Air-pressure type hand sprayers (fig. 119) having a 3- to 4-gallon capacity have been found satisfactory when slightly modified for application of residual sprays. (See appendix D.) A Schrader (tire) valve may be installed in the head of the sprayer tank so that it may be filled with compressed air from an auxiliary source. The sprayer should be fitted with a solvent-resistant hose, a

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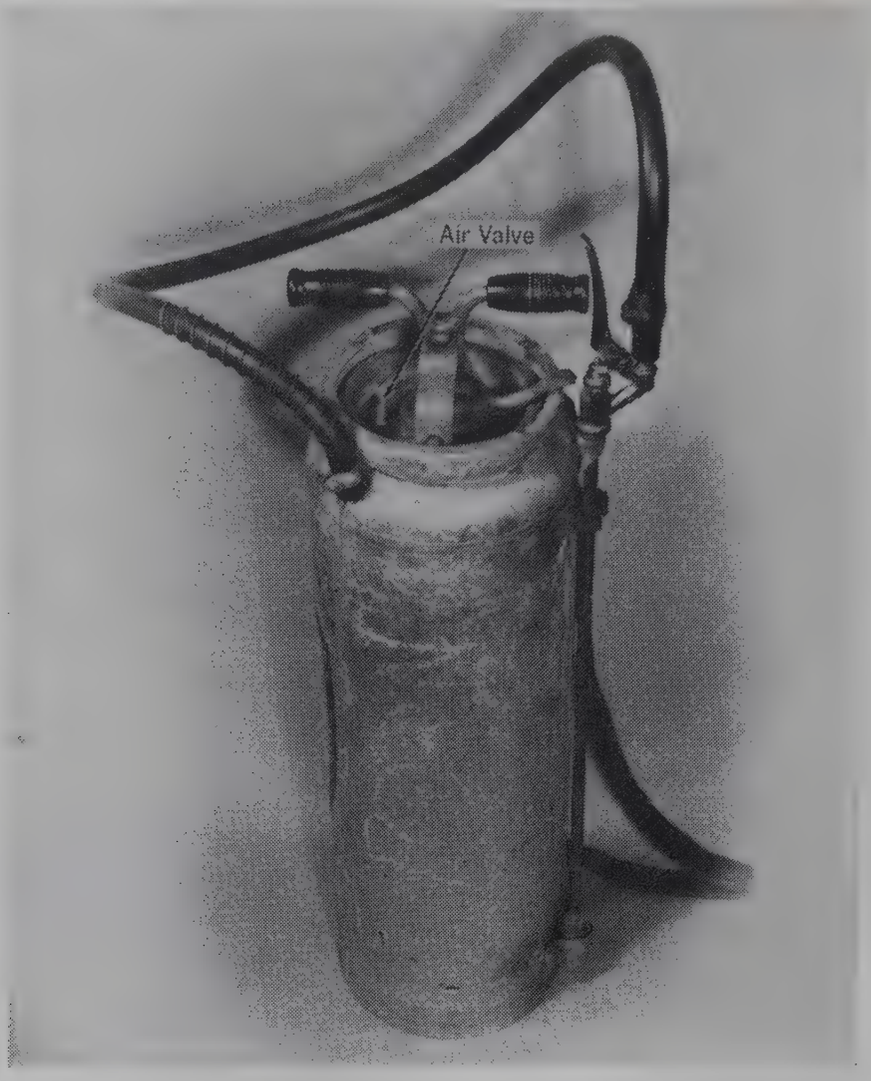

FIGURE 119.—Air pressure sprayer with an auxiliary Schrader air valve.

quick action shut-off valve, a 2-foot extension rod, and a suitable nozzle. Clips may be soldered on the side of the spray tank to hold the gun and to protect the nozzle when it is not in use. A wire or some other device should be soldered on the inside of the tank to denote the correct water level for filling. Thus, the spray emulsion can be made by simply filling with water to the 6-quart mark, adding a quart of the spray concentrate, and shaking the can. Since water can usually be secured on the job, only the spray concentrate need be taken to the field. Five-gallon cans provided with flexible spouts are suitable for the spray concentrate. A crew of two or three is considered satisfactory for hand spraying. Personnel, sprayers, spare parts, tools, cover cloths, can of spray concentrate, and all necessary equipment can be carried in a half-ton pick-up truck.

Another type of hand sprayer suitable for applying DDT is a portable unit with a solution tank, air-pressure tank, and 25 feet of flexible hose.

The piston (or flit gun) type hand sprayer is not suitable as it has a small capacity, is slow and difficult to operate, and has a tendency to atomize the solution. Paint spray guns are unsatisfactory in most

situations for the same reason. When time is not an element and a very careful job is required, paint guns can be used, with some degree of success, if a concentrated spray is employed. Knapsack sprayers are relatively unsatisfactory due to low operating pressures and awkwardness in handling.

Power sprayers—Several types of power sprayers, when provided with a few additions, are satisfactory for residual spraying. The Bean No. 3 orchard sprayer and the Hardie No. 99 × 0105 skid-type sprayer have proven satisfactory when slightly modified to adapt them to the job. (See appendix D.) These sprayer units can be mounted on a half-ton truck with adequate space left for accessory equipment (fig. 120). A hand sprayer is desirable accessory equipment for spraying areas which might be impossible to reach with a hose. A crew of three is generally required for power spraying. The third man can make public contacts, take care of the motors and pumps, prepare the spray emulsion, cover furniture, and aid in spraying. Since the tank of the sprayer has a 50-gallon capacity, a satisfactory emulsion can be made by putting 7 gallons of spray concentrate in the tank and filling with water. When the spray tank is equipped with a drain, the unit can be used as a power mixer. The formulation used is the same as that described for the power mixer. When used as a mixer the intake and overflow hose should be

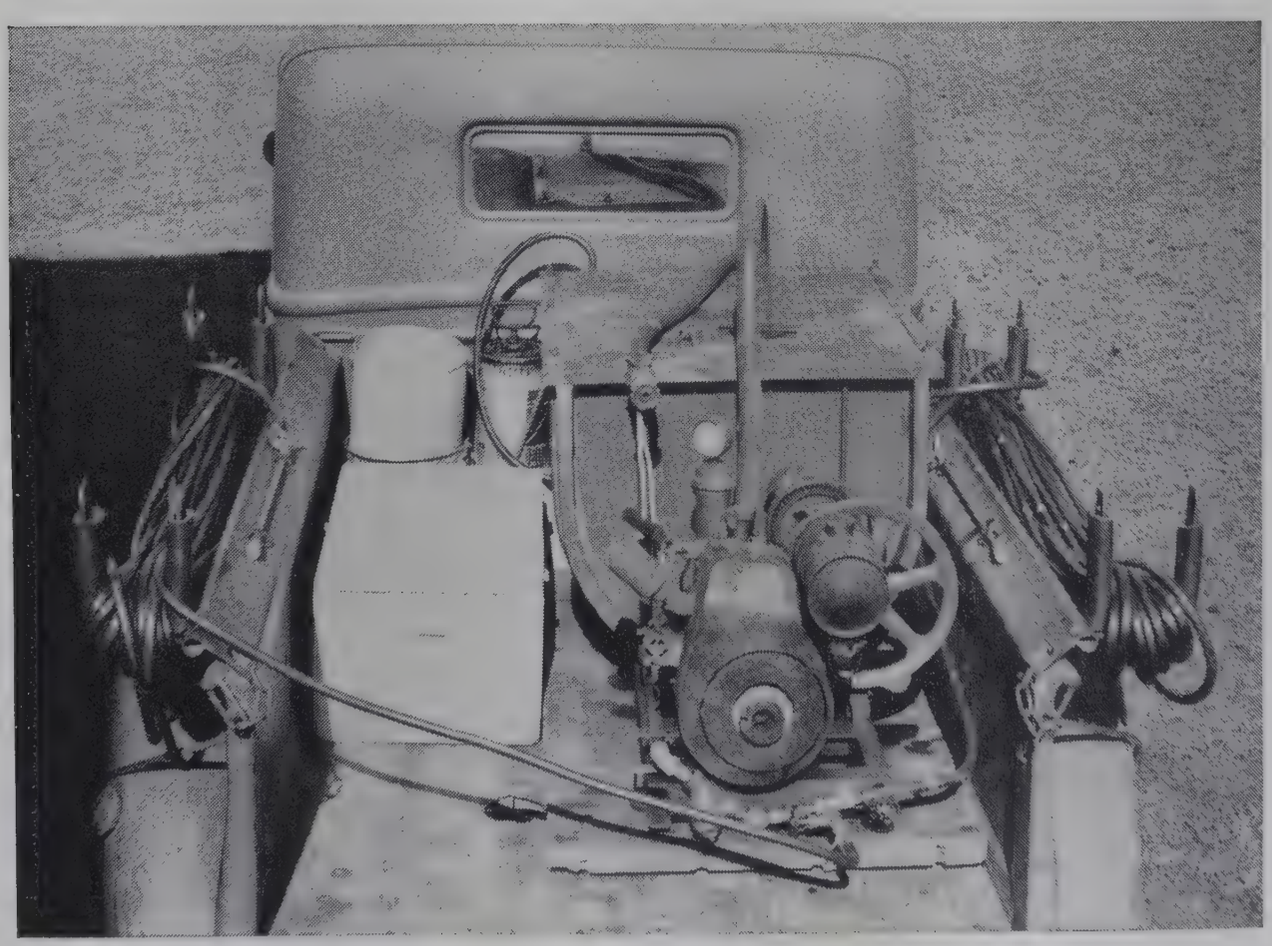

FIGURE 120—Orchard-type sprayer modified for residual spraying.

inserted in a pail of water so the pump will not run dry and damage the plunger cups.

Rate of application and dosage

The amount of spray applied in dwellings is largely governed by the type of surface being sprayed. Although the spray might well be applied at the rate of 2 ml. per square foot or even 1 ml. per square foot, the application of 4 ml. per square foot is considered best for most absorptive surfaces. This rate of application produces visible wetting of the surface and is instinctively employed by the average workman. Since the sprayed areas are readily discernible, it is easy to check the quality of the spraying job. If more concentrated emulsions requiring but 2 ml. per square foot are used on absorptive surfaces the workmen have a tendency to overtreat. With proper technique, 4 ml. of spray per square foot may be applied to rough wood, plaster, paper, plasterboard, and wallboard surfaces without run-off. On smooth, nonabsorptive surfaces such as metal, enameled, or varnished surfaces, it is desirable to double the amount of concentrate in the emulsion and apply at the rate of 2 ml. per square foot. For this application it is best to use a nozzle having half the discharge rate of the regular nozzle so the spraying speed need not be changed.

Dosages varying from 50 to 400 mg. of DDT per square foot may be used with good results, but from the standpoint of cost, durability, and effectiveness, it is believed that a dosage of about 200 mg. of DDT per square foot is best. When applied at this rate a second treatment should be given after an interval of 3 to 4 months.

Nozzles

The nozzle acts as a brush for the application of DDT residues. One which produces uniformly distributed droplets with a minimum of atomization and adequate carrying force to reach the surface being treated is therefore essential. The conical pattern spray nozzles furnished with most commercial sprayers are usable when equipped with a No. 3 ($\frac{3}{64}$-inch diameter opening) orifice plate. However, a nozzle which develops a fan-shaped spray pattern of suitable droplet size and distribution is preferable, since it allows the most rapid and uniform coverage with a minimum of movement. A flat atomizing nozzle giving a 50° fan with a delivery of 0.15 to 0.2 g.p.m. at 40 pounds per square inch is satisfactory for residual spraying. A nozzle having an 80° fan (fig. 121) with a discharge rate of 0.2 g.p.m. has been extensively used. However, the wide spray makes its use somewhat awkward. These nozzles can be used with either hand or power sprayers. (See "Nozzles," appendix

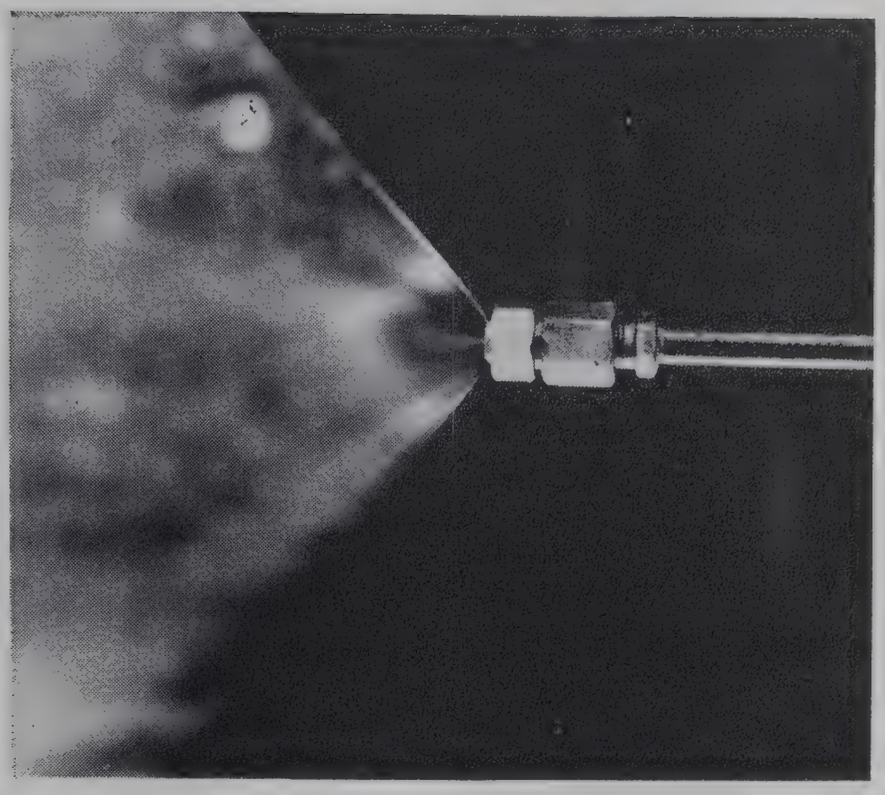

FIGURE 121.—Flat atomizing nozzle delivering a fan pattern spray.

D.) With a nozzle delivering 0.2 g.p.m., about 190 square feet of surface area should be covered each minute if the spray is to be applied at the rate of 4 ml. per square foot. With the use of a nozzle which delivers 0.15 g.p.m., about 142 square feet should be covered per minute. When the power sprayer operates at a pressure of about 60 psi. the 0.2 g.p.m. nozzle has a discharge rate of about 0.25 g.p.m. and about 230 square feet of area should be covered each minute. When the spray emulsion is made and applied as described, a dosage of 200 mg. of DDT per square foot is secured. Since solids in a nozzle of the fan pattern type may change the discharge characteristics, the spray nozzles should be frequently cleaned. This may be accomplished by removing the holding nut and internal parts (fig. 122) without taking the nozzle off the wand. The fine screen strainer may be cleaned with the solvent being used, but it must not be cleaned by poking a needle or wire through the screen. The orifice of a fan pattern nozzle has been carefully machined and is of precise dimen-

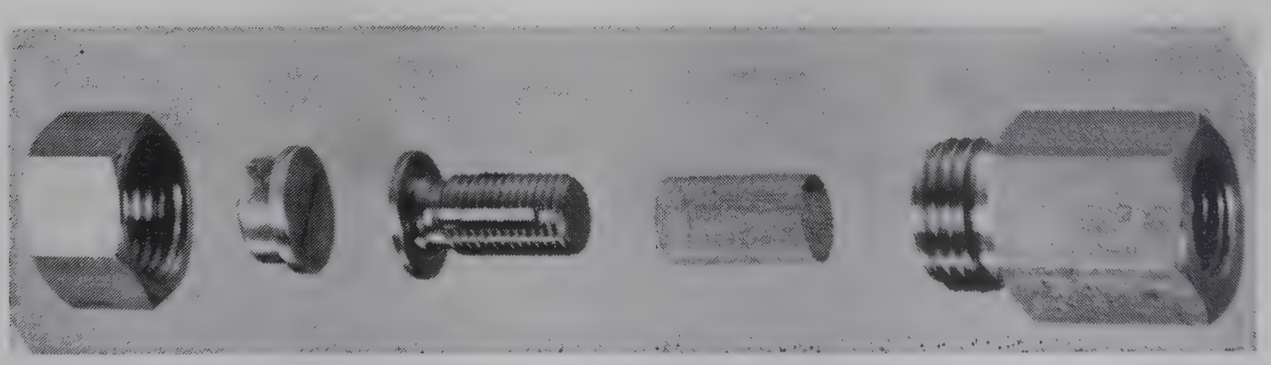

FIGURE 122.—Atomizing nozzle disassembled.

sions. Therefore, care must be exercised in cleaning it. If it cannot be cleaned with solvent alone, use a tooth brush or some similar brush. In reassembling the nozzle care should be taken to insure that all parts are replaced in the proper order and in correct alignment.

Training the crew

If a measured area is to be sprayed an accurate dosage can be secured by the uniform application of a measured amount of spray. In actual spraying operations, however, it is impractical to measure areas or the amounts of emulsion required. It is more feasible to train the crew to apply the emulsion at the desired rate by teaching them to cover a unit area in a unit time. The ability to do this can be acquired only by practice. For training purposes, the area to be covered in 1 minute should be marked off on an outside wall and each crew member taught to cover the area uniformly in 1 minute. He should go over the area again and again until the correct spraying speed is acquired. The spray operator can learn the correct rate more rapidly if a timer calls off the quarter minutes. The nozzle should be held the same distance from the wall at all times. The correct distance is about 25 inches for the 50° nozzle and about 18 inches for the 80° nozzle.

The techniques used in hand and power spraying are similar and depend on the type of nozzle used. With the fan pattern nozzle, the operator begins at the bottom corner of the area and sprays upward with a steady movement of the spray pattern until the top is reached. Without stopping the spray, a step is taken to one side the width of the spray swath and the spray pattern is moved down to the bottom. Spraying is continued in this manner until the entire area is covered. With the conical-pattern nozzle, the spray is applied with horizontal strokes beginning at the top and dropping down a swath width at the end of each stroke.

Surfaces

The type of surface greatly influences the residual toxicity of DDT sprays. The duration of the toxicity is influenced by the extent to which the solvent is absorbed by the surface on which it is applied. The ability of the solvent to volatilize after application is also influenced by the physical and chemical nature of the surface with resultant effects on the distribution and adhesion of the DDT crystals. Untreated wood, plaster, wallpaper, well-dried paints and varnished surfaces, and fabric materials such as mohair, cotton, wool, and canvas retain a residual toxicity for considerable periods. Enameled surfaces, spar varnish, and certain types of whitewash have a moderately high initial toxicity, but they lose it rapidly and are practically

nontoxic in 2 to 6 weeks. Adobe mud, linoleum, outside flat paints, and fresh paints and varnishes give little or no residual toxicity at any time. Toxicity decreases rather rapidly under outdoor conditions. Rain is more important in the loss of toxicity than is sunlight. In one instance, sunlight decreased the toxicity one-tenth in a month whereas 14 inches of rainfall reduced it by two-thirds in the same period. High residual toxicity cannot be expected on surfaces exposed to weathering, and on newly painted or varnished surfaces, linoleum, outside flat paints, or enameled surfaces.

Residual-spraying operations

Plans should be made in advance for each day's spraying so the houses can be sprayed in an orderly manner and with a minimum of travel. The maps of the area serve as the basis for these plans. If possible, the inhabitants of each house should be notified 2 to 3 hours in advance that the spray crew is coming. If this is done and the public meeting has accomplished its purpose, most people will have their homes prepared for spraying when the crew arrives. When a house is properly prepared in advance, only a short time is required for the spraying operations. Cover cloths should always be carried for covering good furniture or varnished floors. As the walls and ceilings of occupied houses represent only about half of the total resting area available to the mosquitoes, every effort should be made to spray as much of the total surface area as possible. Furniture should be arranged with the backs out so the unfinished side can be treated. With hand sprayers, care must be exercised in crowded quarters to prevent damage. If the power sprayer is used spraying should begin in the most distant room so the dirty hose is not dragged through the house. Window shades should be pulled down when spraying around the window to protect the glass from the spray as the DDT deposit is difficult to remove by washing. The operator usually begins at a corner of the room (fig. 123) and proceeds around the room applying the spray in the same manner as was learned in practice. In spraying, it is desirable to give special attention to recognized favored resting places of the *Anopheles* mosquitoes. All portions of the house should be sprayed, including the porches.

Health and safety precautions

Although no known cases of DDT poisoning have developed among spray crews, it is well to take precautions to protect the men against the DDT and the solvents. Many solvents, especially xylene, have distinct toxic effects and often cause more irritation and annoyance than DDT itself. Mixing and spraying crews should have pro-

tective clothing such as long smocks or butchers' gowns to cover their clothing. For indoor work, they should have masks or goggles and respirators. If mixing operations are performed indoors, an exhaust fan is needed to remove the fumes. Solvent-resistant rubber gloves are desirable for the protection of the hands as many solvents cause severe irritation of the skin and DDT-oil solutions may be absorbed directly through the skin to produce toxic effects. Spraying crews should have wide-brimmed hats to protect their necks and faces. For spraying ceilings, the wand should be held at an angle and the operator back up while applying the spray so that it does not fall in his face. A pail of soap and water should be available at all times so the crew can wash their hands and faces at frequent intervals. Spraying crews need a good supply of clean rags for wiping their hands and faces during actual spraying operations and for cleaning their goggles. If the spray emulsion or concentrate is spilled upon the clothing it should be removed immediately and the contaminated portions of the body washed with soap and water. All crew members should be encouraged to take daily baths and to change their clothing frequently.

In operations involving the use of xylene it should be remembered that this is a volatile inflammable material. Proper precautions should be taken to keep xylene vapors from contact with gasoline engine exhausts, sparks, or open flames.

FIGURE 123.—Residual house-spraying with an air-pressure hand sprayer.

SPRAYING COSTS

Residual spraying costs per house differ considerably in different areas due to a variety of reasons. Foremost among these are the size of the houses, their location and accessibility, the availability of water for making the emulsion, the cooperation received from the people, and the efficiency of the crew. The itemized cost estimates given below are based on an extended spraying program of the Public Health Service which involved the treatment of over 250,000 dwellings in 13 States during the summer of 1945. The item for labor does not include man-hours expended for mixing the concentrate but does include time for travel, mixing the emulsion, and actual spraying. The cost for overhead other than field supervision is not included. Treatment of the houses was at the rate of 100 mg. per square feet but material costs are given for treatment at 200 mg. per square feet. The xylene concentrate was used for all spraying.

TABLE 29—*Average cost per house for DDT residual spraying*

	Cost
Labor including time for spraying, field supervision, and charging the sprayer—1.5 man-hours	$1.19
DDT, 0.86 pounds at $0.50 per pound	.43
Xylene and emulsifier	.50
Transportation costs including operation, depreciation, and maintenance	.83
Total	$2.95

When all costs are considered, the average cost per house would be about $3.50 to $5 depending on cost of labor and materials and the size of the operation. Since a treatment at the rate of 200 mg. per square foot generally retains its toxicity for 3 to 4 months or longer, one treatment will probably be sufficient in the northern portion of the malaria region while two will be needed in the southern areas. Two treatments per year will provide a good residual toxicity throughout the malaria season at a total cost of about $6 to $8. This cost compares very favorably with any other malaria control measures now in use.

DURATION AND EFFECTIVENESS OF DDT RESIDUES

Experimental tests have shown that residual deposits of DDT are effective for killing mosquitoes for periods ranging up to 4 to 6 months when applied at a rate of 200 mg. per square foot. In general, residual toxicity is dependent on the rate of application though not directly proportional to it. For example, no significant increase in effectiveness or residual toxicity results from dosages in excess of

200 mg. per square foot, but significant reductions in toxicity have been noted after 8 to 10 weeks when the DDT is applied at a rate of only 25 to 50 mg. per square foot. The exposure time required for DDT to kill *A. quadrimaculatus* mosquitoes (80 percent in 24 hours) ranges from about 40 minutes 2 weeks after spraying to 120 minutes 26 weeks after spraying.

AIR SPRAYING

Air spraying with a finely divided mist of insecticide is an effective means for killing mosquitoes within dwellings, and is of value as a malaria control measure. In a malaria control program on impounded water, air spraying should be reserved as an emergency control measure, which can be rapidly applied in the event of excessive mosquito production and an outbreak of malaria. It is sound practice for any malaria control organization to maintain a relatively small stock of house spray material which can either be applied routinely or distributed to inhabitants when situations may warrant. It is a measure which may also be used by individuals and when widely practiced is a valuable adjunct to the control of malaria. Air spraying is also very effective in eliminating the annoyance caused by mosquitoes and flies, more so in this respect than is residual spraying.

Materials

Pyrethrum is the toxic agent used in most air sprays and is the most toxic material known for adult mosquitoes. Table 30 gives the approximate median lethal concentrations of mists of the pyrethrins and DDT to *A. quadrimaculatus* as measured in spray chamber tests.

TABLE 30.—*Relative toxicities of DDT and pyrethrins to adult* A. quadrimaculatus *mosquitoes.*

Material	Median lethal concentration in mg. per 1,000 cubic feet	
	Males	Females
DDT	7.0	12.0
Pyrethrins	1.0	1.5

Pyrethrum sprays give very rapid knock-down of adult mosquitoes, but at low concentrations recovery sometimes occurs so that small amounts of rotenone or DDT, which give very slow knock-down but high kills, are usually included in the spray. "Gammexane" (see "Benzene hexachlorocyclohexane," ch. VII) is also very toxic to adult mosquitoes and is more than twice as toxic as DDT. Other materials which have been extensively used in knock-

down sprays are Lethane 384 (β-butoxy-β'-thiocyanodiethyl ether) and Thanite (fenchylthiocyanoacetate).

For house-spraying these materials are usually dissolved in deodorized kerosene (Deobase) or in Stoddard's solvent. The concentrations of active materials generally used are pyrethrins, 0.1 to 0.2 percent; DDT, 1 to 5 percent; or Lethane or Thanite, 5 percent. A combination of 0.05 percent pyrethrins and 1 percent DDT is also very effective. More concentrated sprays containing up to 15 to 20 percent DDT, or 1 to 2 percent pyrethrins, may be conveniently used provided the spray is properly dispersed.

Type of spray

For the most effective adulticidal action, the spray should consist of very fine particles, between 10 to 50 microns in diameter. These particles are of aerosol dimensions and will settle very slowly. (See table 22.) Mosquitoes are usually killed by flying into the spray droplets. The presence in the spray of an irritant such as pyrethrum will greatly increase the activity of the mosquitoes and thereby increase the effectiveness of the spray.

Equipment for spraying

The ordinary "flit gun" can be successfully used for air-spraying on a small scale, and will give a spray with particles in the desired size range. Its use, however, is impractical on a large-scale operation where power spray equipment is usually more desirable. Numerous types of pressure spraying units are commercially available. An air compressor with a "paint gun" sprayer is quite suitable for this type of spraying. Dry ice (solid carbon dioxide) units have also been utilized for air spraying.

The "Freon bomb" has been extensively used for insect and malaria control in military operations but is relatively expensive. This bomb consists of a strong steel container fitted with a capillary delivery tube extending from the nozzle to the bottom of the container. The insecticide usually consists either of pyrethrum alone or a mixture of pyrethrum and DDT dissolved in a carrier such as cyclohexanone. The insecticide is dissolved in the propellant gas, generally "Freon 12" (dichlorodifluoromethane, a nontoxic, odorless, noninflammable material), although carbon dioxide and other easily liquefiable gases have been used. A small amount of nonvolatile oil, such as motor oil or sesame oil, is added to prevent volatilization of the aerosol droplets[4]. The "bomb" is operated by opening the nozzle which allows the gaseous Freon at the top of the bomb to force out

[4] Two typical formulations used in these bombs are: (1) DDT, 3 percent; pyrethrins, 1 percent; sesamine 0.3 percent; alkylated naphthalenes, 15.7 percent; and Freon, 80 percent. (2) DDT, 3 percent; pyrethrins, 2 percent; cyclohexanone, 5 percent; hydrocarbon oil, 5 percent; and Freon, 85 percent.

the mixture of insecticide and liquid Freon through the capillary tube. The Freon evaporates quickly leaving a smaller nucleus of insecticide. The particle diameters obtained with this equipment are under 30 microns and can be controlled by the amount of non-volatile material present. A popular model of the bomb contains 16 ounces of material and is considered equal in effectiveness to 1 gallon of standard house spray. Four seconds of spraying is effective for adult mosquito control of 1000 cubic feet of space.

Application of sprays

The technique for the application of air sprays is very different from that employed in residual spraying. In air spraying the objective is to fill the space with a fog of fine spray particles. Particular attention should be given to places favored by adult anophelines such as dark corners, lofts, under beds, under houses, etc. Twenty to 40 milliliters of spray as recommended above should be applied to each 1,000 cubic feet of space to insure kill of mosquitoes. This is equivalent to about ⅔ to 1⅓ ounces of spray.

Where large-scale operations are contemplated, a spray crew equipped with some type of power sprayer should be organized. Two operators in a pick-up truck can treat 40 to 50 rural houses a day. Each house should be sprayed once a week. Added insurance against malaria transmission can be secured by issuing spray and "flit guns" to the inhabitants for daily use in addition to the thorough weekly spraying.

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X. FACILITIES AND OPERATION PROCEDURES

MALARIA CONTROL OPERATION FACILITIES

The physical execution of impounded reservoir malaria control operations will be enhanced with the establishment of adequate equipment, materials, storage, and base facilities. Most run-of-river reservoirs require the strategic location of bases regardless of the control measures to be applied. As the definition, appraisal, and operation must, of necessity, involve boat travel, every reservoir should have at least one base of operation suitable for docking and storing boats. The size of the project may demand additional bases, i.e., subbases to the main base of operation. The number and location of main bases and subbases can be determined only after a careful study of the individual reservoir as to its size, shape, and location of the anticipated work. Generally, it may be assumed that a centrally located base can serve about 150 to 200 miles of shore line.

Base facilities

The location of a base of operation should meet the following requirements:

(1) It should be convenient to the problem areas.

(2) A good all-weather road should be available for trucking in supplies.

(3) The shore line should be steep to simplify dock construction.

(4) The embayment should be of sufficient size and depth to accommodate floating equipment at all water level stages.

(5) There must be adequate protection against wave wash or flood currents.

The water level range of the reservoir will determine the type of base and dock installations. Land-fixed bases (fig. 124) located near the water's edge with a simple retaining wall or dock on piling are usually the most desirable types of installations where topography and water levels permit their use.

On reservoirs having wide pool variations, the base house will necessarily be located inconveniently away from the water's edge unless the site is on steep sloping ground. Docks for land-fixed bases may be built with decks arranged in steps so as to be usable at various water elevations but are usually not as convenient as the "float-type" dock (fig. 125).

FIGURE 124.—Typical land base on reservoir with limited water level range. (Shoal Creek, Wilson Reservoir, Ala.)

In order to eliminate a difficult climb with heavy motors and equipment from the water's edge to the warehouse, lockers may be installed on the floating dock to store equipment during the operation season. The more expensive but best arranged base facility for a reservoir with a fluctuation range of 8 to 20 feet is the complete floating dock and warehouse (figs. 126 and 127).

The chief disadvantage of the floating base is in the anchoring arrangement which must be sufficiently sturdy and flexible to withstand the force of winds and waves at varying lake elevations during

FIGURE 125.—Floating dock and boat slip for reservoirs with wide water-level variations.

FIGURE 126.—Floating base on a reservoir with wide water-level range. (Perryville base, Kentucky Reservoir, Tennessee.)

the winter months. Other adverse features associated with floating equipment are sinking, improper trim, and difficult maintenance of floats; however, these faults may be minimized through careful design and construction.

FIGURE 127.—Floating dock and locker unit. (Big Sandy malaria control base, Kentucky Reservoir.)

The warehouse building (fig. 128) for the subbase should have the approximate dimensions of 14 by 26 feet. The area above the joists may conveniently be used for storing spare equipment such as pike poles, tools, rope, and hose, and should be considered in the selection of the roof design. The floor should be smooth, preferably made of concrete, since timber flooring may warp and rot unless elevated well above the ground surface. The house should have 8 to 10 bins or lockers for storing the boat equipment. A rack for outboard motors is an essential item in the warehouse. A double door is desirable for the entrance and will afford easy access for large objects such as drums and motors. There should be adequate ventilation to minimize mildewing of such equipment as raincoats, boots, and life preservers. Good lighting for sharpening tools, writing reports, etc., must be provided. Only minor repairs on tools, boats, and equipment can be made at subbases, but a sturdy work bench with a good complement of tools set in racks should be provided. A small writing desk is desirable for preparing and keeping operational reports and records. A properly designed base should also include hooks for spare clothing and a shower installation. In rural areas where water under pressure is not available, shower water may be pumped with boat units in the reservoir into steel drums installed above the joists or elevated on framing outside the warehouse.

As it is seldom possible to locate base facilities which will have

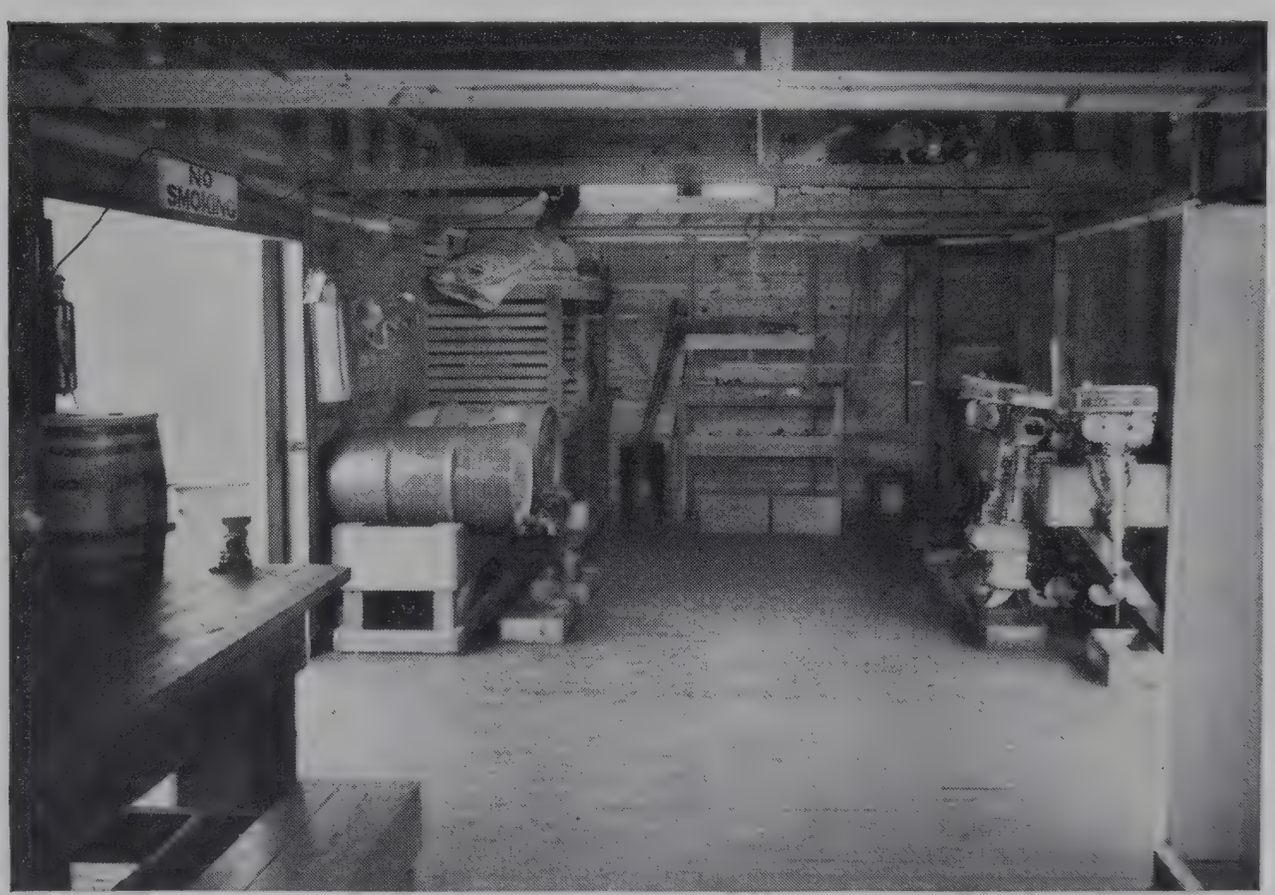

FIGURE 128.—Interior view of a malaria control operation base.

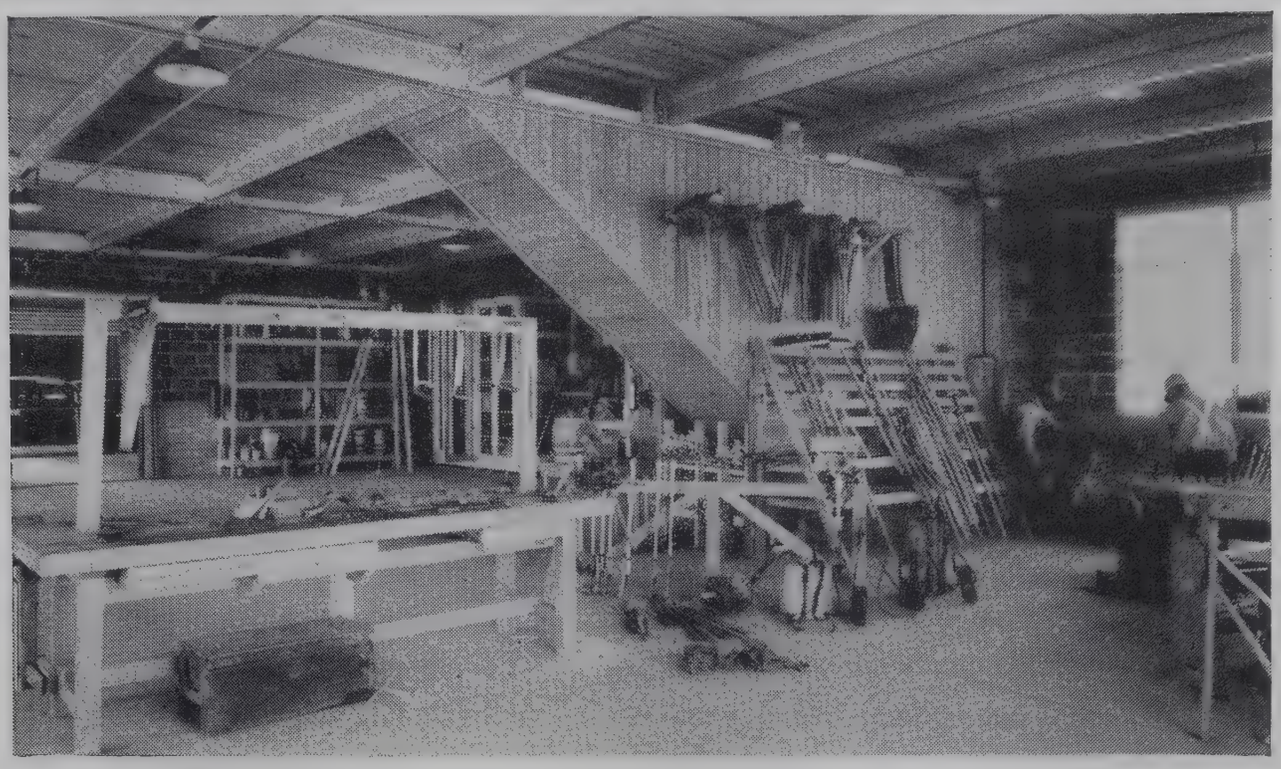

FIGURE 129.—Interior of a main base.

the advantage of urban water and sewerage systems, it is necessary to provide a simple ground water supply and excreta disposal that meet the standards of local health codes.

Storage tanks for gasoline are usually placed underground with properly installed vents but they may also be incorporated in the floating dock design. Subsurface storage tanks must be placed in well-drained pits above the highest water table, otherwise the tank may float out of the ground when the level of the lake is high. Due to the small hazard, larvicide tanks may be installed above the ground on concrete or treated timber footings. Steel tanks are recommended in preference to wooden tanks which tend to leak. Discharge lines from both larvicide and fuel storage tanks should be carried to the dock for the convenience of servicing the boat units.

While desirable, it is not always practical to have boathouses in which all the malaria control boats can be stored. Boathouses should usually be provided for launches and inspection craft and may be either of a fixed or floating type. Care should be exercised in the design of boathouses to insure adequate length, headroom, and catwalk space. The doors should be designed so they will be easy to operate and can be opened and closed from inside and outside the house. Pulley and rope systems are not as satisfactory as a direct lever-arm arrangement.

An inventory of a typical malaria control subbase is given in appendix D.

The main base of operation serves as a concentration point for delivery and storing bulk supplies and maintenance of malaria con-

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trol equipment. It is desirable to have the main base centrally located in the reservoir but often it may be more economically located at the dam along with other plant maintenance facilities. Important factors in the location of the main base are:

(1) Easy access by reservoir, highway, and, if possible, railroad.

(2) Electrical power and light utilities.

(3) Pressure water supply.

(4) Telephone communication.

The size of operation will dictate the required development of the main base. On very small projects these bases may be only slightly larger than the average subbase, while on larger operations quite an extensive structure may be required (fig. 129). The main base house should have ample space to provide for a warehouse and stockroom and a boat repair section. The boat repair section may be separated into four divisions:

(a) Boat removal.

(b) Boat cleaning.

(c) Motor repairing and storage.

(d) Hull repairing and painting.

The removal of boats from the water may be accomplished by several methods. A sling and crane may be used, but care must be exercised in adjusting the slings to prevent damage to the hull, or boats may be placed on a dolly or rail handcar and transported to the boat cleaning and storage area. An inclined ramp, either concrete paved or rail track, is favored in the absence of heavy crane equipment.

The motor repair areas should be free of dust, have smooth flooring, and should be well lighted. Overhead monorail chain-falls will be useful in handling heavy motors.

The boat repair and paint shop should be separated from the motor repair shop and is usually located close to the boat storage racks. The merits of storing boat hulls on the inside or outside are debatable, but as a general rule the advantages and economy of outside storage of wooden hulls appear to offset the disadvantages. However, they should always be stored on racks above ground.

The requirements for the proper mixing of dust and oil larvicides have been discussed in chapter VII. A separate building should be provided for receiving, mixing, and shipping ingredients. Larvicidal mixing plants should be conveniently located at a point served by road, rail, and water transportation.

Boats

The boats used in malaria control operations should be designed to have the following principal features:

1. Ultra-shallow draft, stable, seaworthy, maneuverable, and with control in reverse gear.
2. Strength obtained by chine construction, close-frame spacing, 1-inch planking, and heavy head and stern blocks.
3. Bow designed to permit "dry-footed" landings and to withstand bumping submerged logs and stumps.
4. Protection provided for propellers and underwater gear.
5. Powered by a reliable engine (either inboard or outboard) with good performance and low maintenance costs.

Boats for malaria control operations require an exceptionally shallow draft for carrying equipment and personnel in shallow water while larviciding, dipping for larvae, and inspection. The shallow draft may be obtained through the use of a flat-bottomed hull and the increased buoyancy through greater beam and length dimensions. For safety reasons, it is important that the hull be sufficiently long to take the short rolling waves often occurring on impounded water. Hulls which may operate on a reservoir of any considerable size should not be less than 18 feet long and preferably longer. The hull should have decking fore and aft with a coaming all around the open cockpit to provide added protection against spray and waves. Greater maneuverability of these boats may be secured by the use of a relatively large rudder located directly behind the propeller so as to get maximum rudder action against the thrust of the propeller.

The hull must be exceedingly strong to withstand operations in shallow water where stumps and other submerged obstructions may be encountered. Cypress wood has been found to make excellent planking. However, hulls made of aluminum or magnesium alloys, which require less maintenance, may in time replace wooden hulls.

A typical utility hull suitable for larvicidal oiling or transporting men and equipment on maintenance operations is shown in figure 130. (Dimensions for utility boats shown in table 31.)

The "spoon-bill" type bow design is essential for operating along the shallow margin of a reservoir and for beaching. The bottom planking of the bow should be protected by installing half-round battens spaced 4 to 6 inches apart and extending back to the third or fourth rib. The over-all clearance of the underwater gear may be kept at a minimum depth by a severe stern rake. The shaft, bearing, and wheel can be protected with a diamond plate guard (fig. 131). This will offer protection from all sides and, being stream-

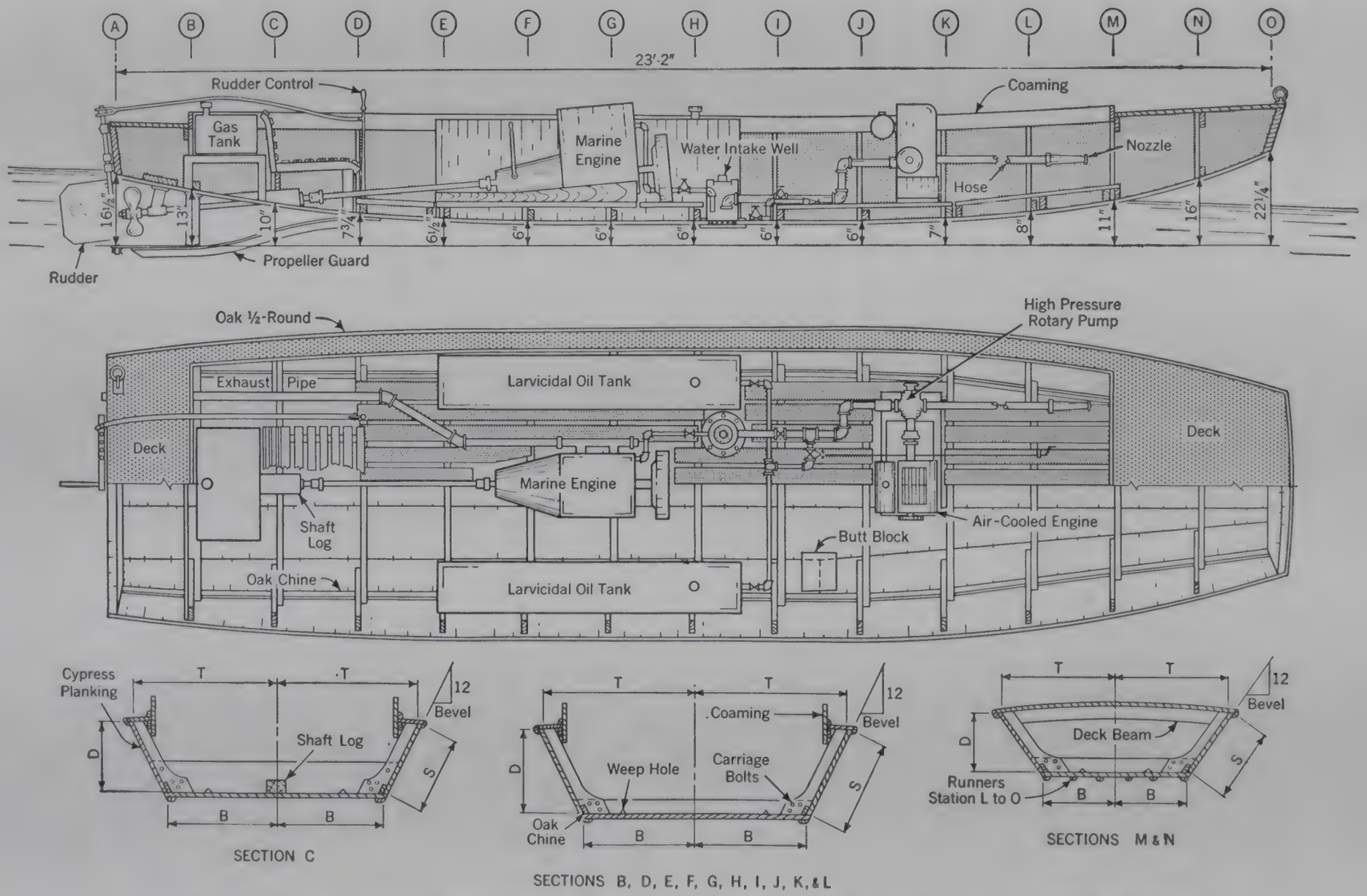


FIGURE 130.—Principal features of a boat for malaria control operations on impounded water.

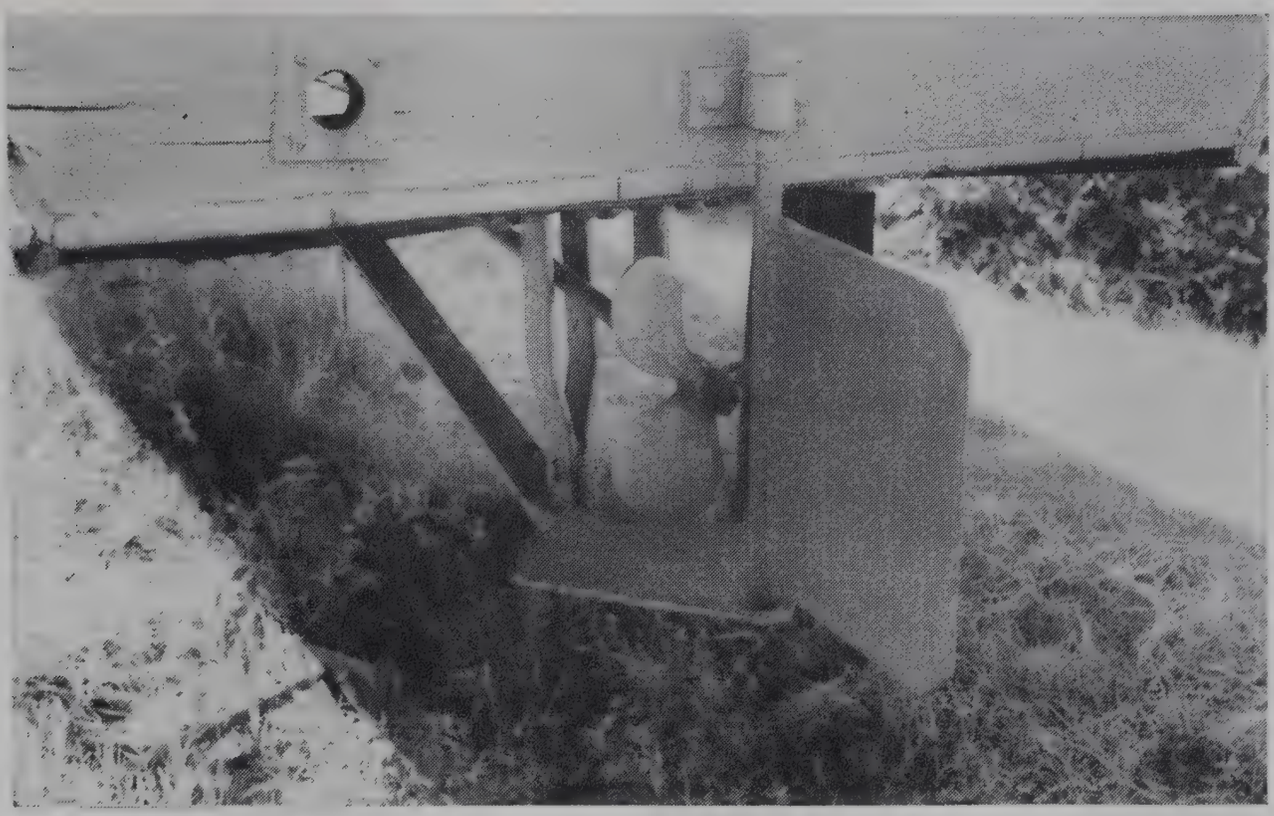


FIGURE 131.—Diamond-shaped propeller guard for operation in shallow water.

lined, offers a minimum of resistance to movement through the water.

Most malaria control boats are relatively slow (5 to 10 miles per hour); for inspection work it may be desirable to obtain the speedier, commercial model hulls or launches (fig. 132). In reservoirs where inspection boats have to operate in channels, and have difficulty in approaching the shore at low lake levels, inspections may best be accomplished by an automobile meeting the utility type inspection boats (fig. 133) at prearranged times and places.

The number of boat units required on a reservoir depends largely upon the amount of treatment area and the type of malaria control

FIGURE 132.—Commercial model inspection launch.

FIGURE 133.—Utility inspection launch for operating in shallow water.

operations. In a well-prepared reservoir having good water level management, with a limited hand and boat larvicidal program utilizing an airplane for large acreages, an estimate of boat units required including larvicidal, inspection, and transportation may be made from the following empirical formula.

$$\text{Total boat units required, } B = 0.2\ T^{0.8}$$

Where T = Miles of proposed treatment

The distribution, number, and type of boat units required can be determined by location of treatment areas, access roads and bridges, and larvicidal and shore-line maintenance operations.

TABLE 31.—*Dimensions for utility boat hull shown in fig. 130.*

Station	T		B		S		D		Bevel
	Ft.	*In.*	*Ft.*	*In.*	*Ft.*	*In.*	*Ft.*	*In.*	*Inches*
A	2	6	2	¾	1	0	0	11	7½
B	2	10¾	2	1¾	1	3¼	1	1⅝	6
C	2	10	2	1¾	1	6⅜	1	4⅞	6
D	2	10¾	2	2	1	8½	1	6⅜	6
E	2	11½	2	2	1	9¾	1	7½	6
F	2	11¾	2	2⅛	1	10	1	7¾	6
G	3	0	2	2¼	1	10	1	7¾	6
H	3	0	2	2¼	1	10	1	7¾	6
I	3	0	2	2¼	1	10	1	7¾	6
J	2	11½	2	1¾	1	10	1	7¾	6
K	2	10⅝	2	⅞	1	10	1	7¾	6
L	2	9	1	10⅛	1	10	1	7	7
M	2	6½	1	7⅜	1	8½	1	5	8
N	2	2⅞	1	4¾	1	5	1	1⅛	9
O	1	9	1	3		11		9	9

Each malaria control boat assigned either to larvicidal, shore-line maintenance, or inspection activities, should have the following standard equipment: Life preservers conveniently placed for ready

use by each person on board; two carbon tetrachloride fire extinguishers, 1-quart capacity, located in the bow and stern for open boats; cabin boats should have an additional 2½-gallon foam or 15-pound CO_2 extinguisher; paddles; pike pole; whistle; water keg; and tool box. The contents of a tool box should consist of:

Stillson wrench, 18-inch	Pliers, 8-inch
Stillson wrench, 14-inch	Pliers (round nose), 6-inch
Crescent wrench, 12-inch	Screwdriver, 10-inch
Crescent wrench, 10-inch	Screwdriver, 6-inch
Crescent wrench, 8-inch	Screwdriver, 3-inch
Crescent wrench, 6-inch	Ball hammer
First-aid kit	Pilot rules (where required)

On the utility boats the propelling motor should be of rugged design and construction with normal speeds for steady service under 1,500 r.p.m. The horsepower requirements should be chosen to provide a cruising speed from 8 to 12 miles per hour. Generally, an inboard unit built for heavy duty will provide more reliable service under severe working conditions than the lighter outboard units. A reverse gear is essential for inboard units. The high initial cost

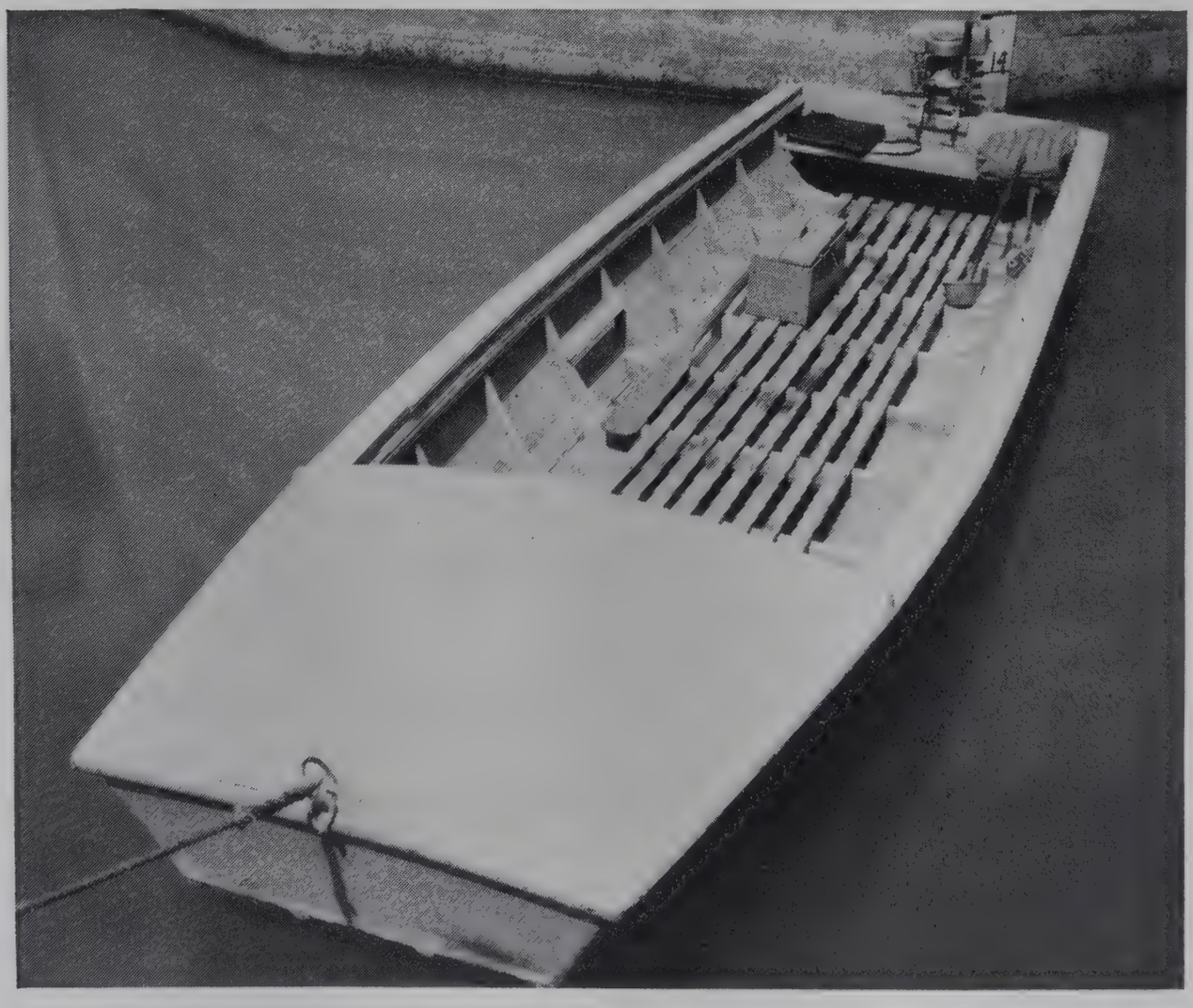


FIGURE 134.—Utility outboard motorboat equipped for larvae and adult mosquito inspection.

and maintenance and limited maneuverability are the major disadvantages of inboard equipment. Utility hulls with outboard motors should have provided, in addition to the standard clamps for fastening, a short chain arrangement to prevent the motor from jumping off and being lost overboard when an obstruction is hit. Frequently, it is advantageous to use two motors, a 15- or 22-horsepower for long straight runs, and a 10-horsepower motor which will revolve 360° for operating close to the shore.

The outboard-powered hulls are speedier, more maneuverable, and require less maintenance cost. The disadvantages of this type of motor are: relatively short life, difficulty in handling and operating, and frequent minor repairs such as changing spark plugs, cleaning out carburetors, etc. Figure 134 shows an 18-foot outboard-powered utility hull prepared for larvae inspection. (Note safety chain on motor, tool box, and other standard equipment previously listed.)

In the interest of safe and efficient boat operation it is essential that sufficient tie rings be installed and that mooring arrangements be designed to minimize tripping hazards. Moorings should provide for variations of water levels and prevent contact between hulls. The handling of gasoline fuel is hazardous and spillage, especially in motor compartments and bilges, must be prevented. Refueling should be undertaken with care, using either a can approved by the Underwriter's Laboratories or a gasoline discharge hose with a quick-opening valve. A wire-gauze filter funnel will reduce spillage and insure more reliable engine operation. All gasoline tanks should have cut-off valves on the fuel feed line. Accumulations of water in the boat should be removed regularly. Where a number of boats are based together, a small pump will greatly facilitate emptying the boats after a heavy rain. The intake valve for the cooling water supply on inboard boats must be closed after the boat is moored. If there is any likelihood of freezing, the motor block and pump must be thoroughly drained.

Tools and equipment

There are a large number of small tools and equipment which are necessary to carry out the numerous malaria control operations. As in any field operation, careful consideration should be given to the selection of tools and equipment which are most suitable to the particular task at hand. In general, most of the items required can be obtained on the commercial market, but in some instances it may be desirable to modify commercially available items or develop new equipment in order to secure the most effective and efficient operation. There should always be a constant search for new or improved

tools which will accomplish the required work more efficiently, with greater safety and less maintenance. A list of various tools, supplies, and equipment most commonly employed on impounded water malaria control operations together with specifications for their purchase is given in appendix D. Specialized items not covered in this appendix are principally larvicidal and adulticidal materials, herbicides, and equipment for mixing and application. These specialized items of materials and equipment are either discussed in the various chapters dealing with the field measures of shore-line maintenance, larviciding, mosquito-proofing, and house-spraying, or can be found in appendices C and E. The specifications listed may be of value in preparing requisitions to enable the procurement of good quality, standardized items.

Airplane loading fields

Airplane loading fields for larviciding should be located so as to minimize nontreatment flying time and where there is a suitable landing area of at least 300 by 2,000 feet (fig. 135) . The field should have a smooth, well-drained surface free of ditches and ruts. Grades up to 1 percent are not objectionable, but rolling terrain which would necessitate major grading should be avoided. Adequate means should be provided to prevent unauthorized persons or stock from entering the landing area. The fields need not be perfectly level but should be smoothed by dragging and planted with a good grass turf such as Kentucky bluegrass or Bermuda grass. A suitable turf may be quickly obtained by sowing Bermuda grass at a rate of 25 to 30 pounds per acre or a mixture of Kentucky bluegrass and redtop at 100 to 150 pounds per acre. On moist soils, lespedeza sowed at 25 pounds per acre will also give a good turf. Arrangements must be made to mow the fields at least twice during the growing season. This service may often be obtained from local farmers in return for the hay crop.

Practically every loading strip has a favored approach and in the absence of wind, pilots will invariably enter from that side. The storage house for larvicidal materials should be located downfield from the favored approach in order that no time is wasted in taxiing to the loading position after landing.

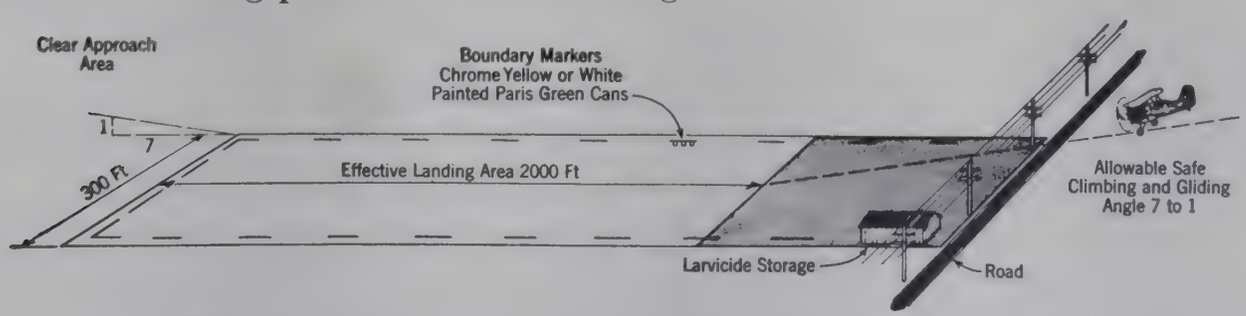


FIGURE 135.—Sketch of a landing strip for airplane larviciding.

The size of the storage house will be determined by the larvicidal material to be applied. Dust larvicides will require dry storage space for 10 to 20 tons of dust. It is advisable, when possible, to store a small amount of aviation fuel on the strip for emergency refueling of the airplane. Well anchored tie-down "eyes" and chains should be provided for securing the plane overnight or during stormy weather.

FIELD OPERATIONS

Administration and personnel

In general, the execution of malaria control measures on a reservoir is under the direction of a sanitary engineer. On larger reservoirs there will usually be available epidemiologists and biologists who will collaborate in the planning and appraisal of the program. Assisting the engineer with the actual field operations are foremen or supervisors who are trained in directing and appraising the field activities of malaria control. Reporting to the general foreman are the subbase foremen who are responsible for boats, supplies, and equipment assigned to their base, and for directing the labor forces in the various measures of larviciding, house-spraying, and shoreline maintenance as required. The work is usually outlined and assigned to the subforemen by the general foremen after field findings and inspections have been analyzed with the sanitary engineer in charge. As no routine plan of control can be followed throughout the breeding season, detailed field plans of operation and field appraisal of efficiency and adequacy of the measures applied must be issued on a day-to-day basis. It is the responsibility of the field organization to make the necessary reports in accordance with procedures discussed under "Reporting." These operating records incorporated with field engineering surveys may be used as the basis for formulating future programs, estimating quantities of work and materials, costs, and for considering the advisability of making certain permanent shore-line improvements as discussed in chapter IV.

In figure 136 is shown an example of an organization chart for carrying out malaria control operations on an impoundment. Of course, the size of the organization will be dependent upon the malaria control problem and the size and type of reservoir.

On well-prepared and maintained reservoirs all positions below the general foreman are of a seasonal nature. However, in some instances personnel may be used during the winter on maintenance of equipment. Foremen, boat operators, inspectors, and laborers may usually be recruited in the vicinity of the various bases. The most desirable employee is one who operates a small farm but is willing, when needed, to work with the malaria control forces. Adult

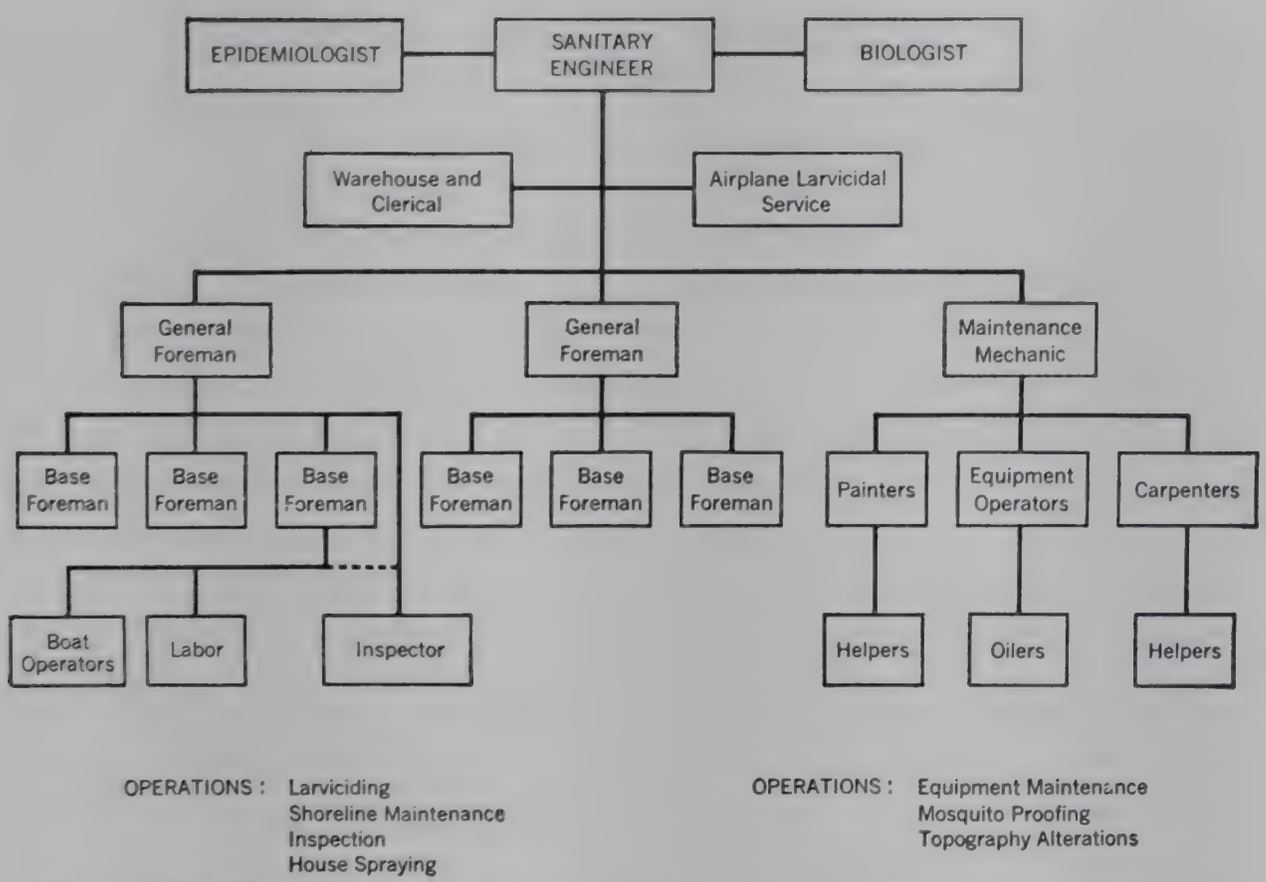


FIGURE 136.—Typical organization chart for malaria control operations on large impounded water projects.

and larvae inspectors may be obtained from rural school teachers, college students during summer recess, or other intelligent and dependable individuals who can learn mosquito identification, inspection, collection, and dipping techniques in a short time. The base foreman should be a leader who can receive and transmit daily instructions to the malaria control crew, assume responsibility for equipment and materials, and prepare reports of the activities.

The general foreman or supervisor is an aide to the sanitary engineer and provides the necessary contact between office and field. He should be well versed in mosquito control measures, be a keen observer of shore-line and reservoir conditions, and be capable of interpreting field instructions to the base personnel. The general foreman should report to the main base of operations daily, especially during the mosquito-breeding season.

Malaria control operations

Spring and summer field operations consist primarily of locating and larviciding anopheline breeding areas, minor drainage maintenance, the appraisal of control measures through adult and larvae collections, and the institution of emergency measures such as mosquito-proofing and house-spraying when necessary.

During the early part of the season when mosquito production is light, the only personnel required are men to carry out necessary

inspections and to apply limited amounts of larvicides. As the season progresses, and in the absence of airplane larviciding equipment, larvicidal units should be increased so that larvicidal treatment can be rapidly expanded should emergency situations arise. Any residual house-spraying or mosquito-proofing programs should be carried out prior to any significant anopheline mosquito production. To obtain maximum benefits residual house-spraying should be deferred until immediately prior to initiation of mosquito-breeding. In late summer, larvicidal operations usually decrease with water-level recession and the forces may be used on drainage and aquatic growth control maintenance.

The requirements for base personnel, as a rule, reach a peak during the fall in order to complete the necessary shore-line maintenance before the weather becomes unfavorable for these operations. Fall operations largely consist of conditioning the margins of the reservoir so as to eliminate or minimize situations which otherwise would be favorable for mosquito propagation the following season (see ch. VI, Shore-line Maintenance).

After the completion of fall operations the bases should be prepared for the winter season. This should include assembly of boat equipment at the main base of operations, preparation of firebreaks around storage houses, storage of such equipment as hose, rope, and removal of condensate water from the storage tanks and discharge lines. It is desirable to have the storage tanks low or empty during the winter period. This is especially true for gasoline which becomes gummy after prolonged storage.

REPORTING

General

Reporting of field activities is essential to the operation of a malaria control program for the following reasons: (1) to indicate where control measures are needed; (2) to determine the effectiveness of control measures; (3) to furnish information for the payment of salaries and contractual service; and (4) to give specific information regarding the progress of the program in *(a)* various measures applied, *(b)* units of work and materials required, and *(c)* location of activity. The foreman's daily report of activities serves as the basis of all subsequent reporting and should be complete, accurate, and yet not burdensome to field personnel. Daily reports should be submitted in duplicate from various bases of operation—one copy for payroll and cost-accounting purposes, and one copy for the engineer in charge. A continuous progress record should be prepared of the various control measures applied, their location, and amount of materials and labor used. These tabulations may be sum-

marized and combined with entomological reports into the engineer's weekly report of the mosquito control operations. These reports should be in sufficient detail to keep interested persons and agencies currently appraised. It is desirable to prepare a season or calendar year report incorporating essential field data broken down into major operations by reservoir zones and types including epidemiological and entomological findings. From the calendar year report a critical analysis of the malaria control program, as executed, may be made to ascertain success or failure and guide future program planning.

Daily reports

Figure 137 is a foreman's daily report of field operations. Basically, the form for reporting daily activities should be designed to record all pertinent information with respect to personnel, equipment, and materials employed in terms of operation, location of work, and progress completed. With respect to personnel, the listing should include names, rate, and hours of work for the pay roll, and a time distribution column for reporting and cost-accounting purposes. With respect to equipment and materials, space should be provided for listing equipment, number or name, quantities of materials by classes, and amount and time used. Usually, the shore line of a reservoir is divided into mile stations to facilitate the reporting of entomological data and field operations. The form should have room for including any request for supplies or remarks pertinent to the day's operation, and a space for keeping a record of supplies received at the base.

In instances where major equipment is employed which by its nature would not be under the supervision of the base foreman, a special report is usually required. For example, a daily flight report for airplane application of larvicide should include identification of equipment, area of operation, larvicide used; a break-down of flying service rendered including ferrying and actual larviciding time; source and amount of larvicide applied; areas treated in shoreline miles and acres; and any other pertinent information as local conditions may require.

Weekly reports

An engineer's weekly report of current activities is shown in figure 138. This form should incorporate a sketch map of the reservoir on which are shown shore-line miles, operating facilities, adult catching stations, major population centers, and orientation points such as county lines and names of larger tributary streams. Space should be provided for tabulating personnel, equipment, and materials used

DAILY REPORT OF MOSQUITO CONTROL WORK

RESERVOIR Pickwick BASE Spring Creek DATE 6-1-38

DAILY TIME DISTRIBUTION

NAME	HRS	RATE	TOTAL	OPERATION * 1 Oiling	2 Dusting	6 Drainage	4 Drift Removal
James Statom	8	.91		3	1	4	
Bob Brown	8	.70		8			
M. Matlock	8	.70			8		
J. Astor	8	.60			8		
R. Gammel	8	.60		8			
N. Steveson	8	.60				4	4
Bill Carter	8	.60				4	4
TOTALS	56			19	17	12	18

PROGRESS Ditching at mile 175 - 50 lin. ft.
Drift removal at mile 192 - 30 lin. ft.

EQUIPMENT NO.	LARVICIDES Tank	Oil Gals.	P G Dust Pounds	HERBICIDES Pounds	FUEL Gas Gals.	Oil Qts	MOTOR OPERATED Hours	Min	PROGRESS *	From	To	Miles	Acres
54031	2	52	—		10	1	6	0	1	145	183	3	
54032			100		8	0	4	30	2	210	218		5
TOTALS	X	52	100		18	1	10	30				3	5

* 1 Oiling 2 Dusting 3 Rebrushing 4 Drift Removal 5 Aquatic Growth Control 6 Drainage 7 Others

SUPPLIES RECEIVED

Oil _____ Gal.
P G Dust _____ Lb
Gasoline _____ Gal.
Motor Oil _____ Gal.

REMARKS Growth invasion 413.4

Need shear pins and drinking cups

James P. Statom
Foreman

FIGURE 137.—Daily report form.

during the week and season, and results of mosquito inspections. The approximate location and extent of activities may be indicated on the map by a suitable legend. Unusual conditions and activities may be recorded on the form as needed. A small graph should be provided for plotting the daily pool elevations to indicate the level of the lake during the period. The water levels in the upper reaches of long reservoirs may be affected by backwater in which case it may be desirable to plot water levels at two or more points in the reservoir. It is also desirable to show the extent of a significant invasion of vegetation on the water level graph. The weekly report is usually accompanied by a tabulation of larvae and adult mosquito inspections for that week (fig. 139). The report may be duplicated by ditto, blueprint, or mimeograph process for distribution. In actual practice, the various items shown in the legend (fig. 138) are indicated on the map by color rather than by the symbols shown.

Calendar year or season report

The engineer should assemble all data along with supplementary charts and maps to summarize the malaria control operations as executed during the calendar year. It is essential that the report include a brief narrative covering field conditions, operating facilities, water level management, weather conditions, and any other factors which may have had a bearing on the season's operation. The narrative is vital for evaluating and interpreting the tabulations of activities. The final tabulation should give all field data by reservoir subdivision or zone and problem area. Included may be the results of malaria surveys and mosquito inspections, expenditures by classification into larvicidal operations, and shore-line maintenance, and the cost of malaria control per mile of reservoir shore line and the cost of protection per capita. Such a detailed analysis of a season's operation on Pickwick Reservoir, Alabama, is shown in table 32. It is desirable to include small-scale maps showing the progress of work and charts indicating the influence of water level management and antilarval measures on the production of anopheline mosquitoes throughout the completed season (see fig. 59).

LARVAE INSPECTIONS

	BEFORE TREATMENT				AFTER TREATMENT			
	Number of Dips		%	Aver	Number of Dips		%	Aver
	Total	Positive	Pos	Dip	Total	Positive	Pos	Dip
Week	1,879	562	30	0.8	502	40	8	0.2
Season								

MOSQUITO CATCHING STATION INSPECTION

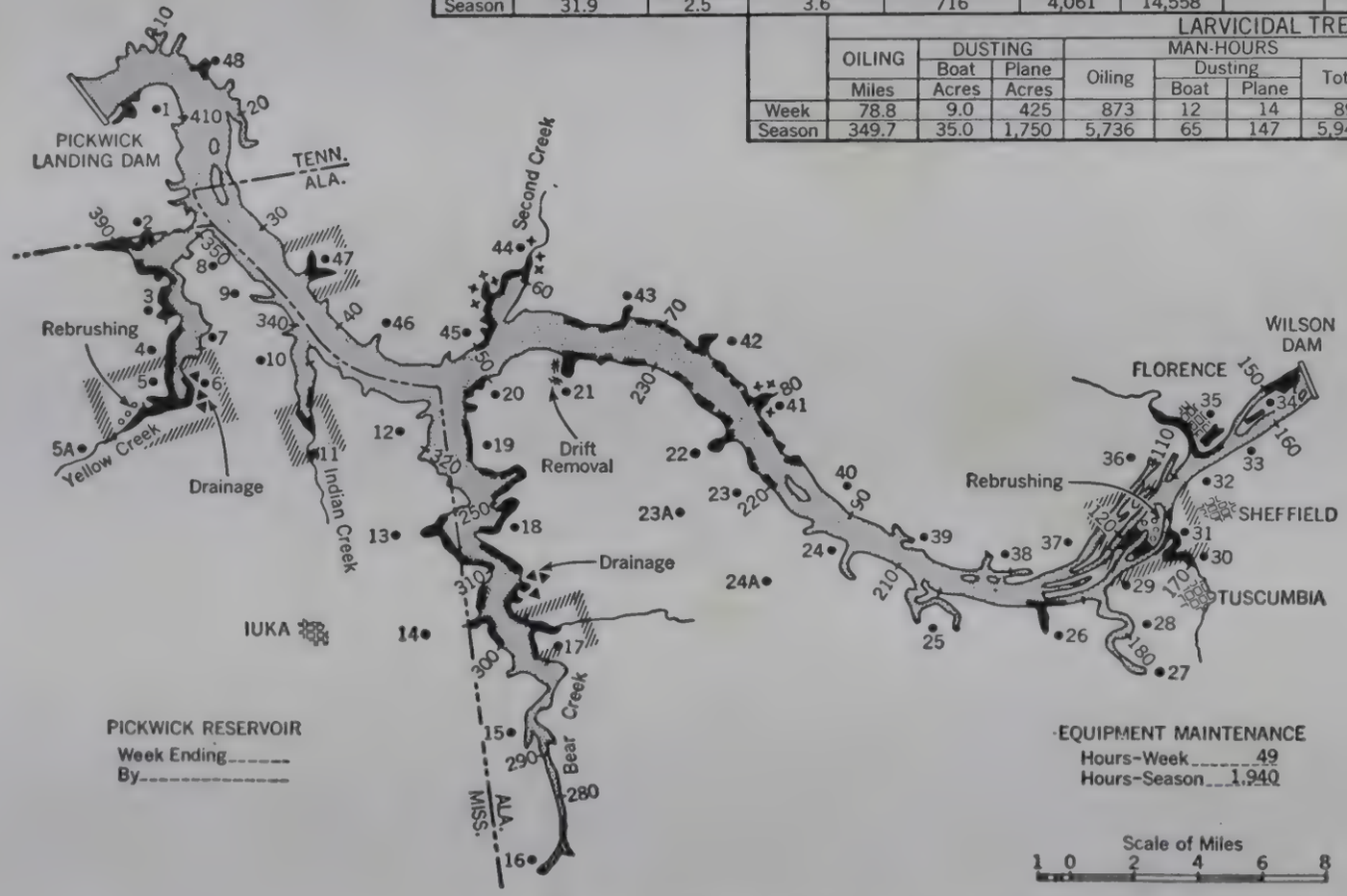
	TYPE I AREAS			TYPE II AREAS			TYPE III AREAS			SCREENED AREAS		
	No. of Sta	Tot Fem A. Quad.	Aver Sta	No. of Sta	Tot. Fem A. Quad.	Aver Sta	No. of Sta	Tot. Fem A. Quad.	Aver Sta	No. of Sta	Tot. Fem A. Quad.	Aver Sta
Week	7	55	7.9	6	48	8.0	15	15	1.0			
Season	105	1,060	10.0	90	757	8.4	225	637	2.8			

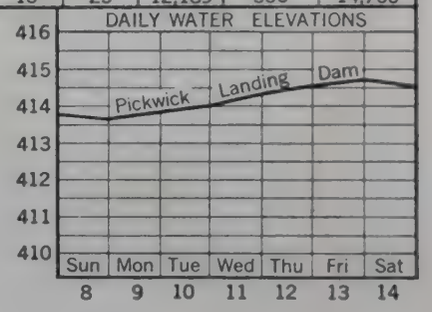
SHORELINE MAINTENANCE

	GROWTH REMOVAL	DRIFT REMOVAL	AQUATIC GROWTH CONTROL		DRAINAGE – FEET		MACHINE HOURS	MAN-HOURS				
	Acres	Miles	Acres	Herbicides Gallons	New Ditches	Old Ditch Cleaned		Growth Removal	Drift Removal	Aquatic Growth	Drainage	Total
Week	3.1	0.1			320			230	16		50	296
Season	31.9	2.5	3.6	716	4,061	14,558		2,640	729	1,089	1,930	6,388

LARVICIDAL TREATMENT

	OILING	DUSTING		MAN-HOURS				PLANE FLYING TIME		OIL USED	DUST USED POUNDS	
		Boat	Plane		Dusting							
	Miles	Acres	Acres	Oiling	Boat	Plane	Total	Hours	Minutes	Gallons	Boat	Plane
Week	78.8	9.0	425	873	12	14	899	2	25	2,885	90	3,200
Season	349.7	35.0	1,750	5,736	65	147	5,948	13	25	12,189	350	14,700





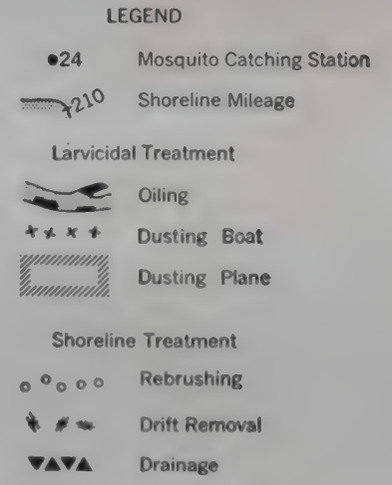


FIGURE 138.—Weekly report of mosquito control operations.

TABLE 32.—*Analysis of malaria control operations for Pickwick Reservoir,* 1942.

Zone	Area	Miles shore line	Houses	Population	Population per mile of shore line	Average *A. quad.* sta. count	Malaria survey (blood slides)			Malaria control operations								
										Larvicides			Shore-line maintenance			Total cost	Cost per mile	Cost per capita
							Slides	Positive	Percent Positive	Cost	Per mile	Per capita	Cost	Per mile	Per capita			
	Total 1-mile area	496	6,340	31,700	64	4.6	326	0	0	$23,684	$48	$0.75	$19,151	$39	$0.60	$42,835	$86	$1.35
	Total type I zones	100	1,040	5,200	52	8.6	274	0	0	11,316	113	2.18	11,255	113	2.16	22,571	226	[1]4.34
	Total type II zones	88	328	1,640	19	6.7	52	0	0	4,761	54	2.90	5,139	58	3.13	9,900	113	6.04
	Total type III zones	308	4,972	24,860	81	1.9	.....	.....	.....	7,607	25	.31	2,757	9	.11	10,364	34	.42
	Type I Zones																	
2	Upper Yellow Creek	17	85	425	25	22	146	0	0	6,183	364	14.55	4,049	238	9.53	10,232	602	24.08
8	Collier's Slough—Seven Mile Island	83	955	4,775	58	3.1	128	0	0	5,133	62	1.07	7,206	87	1.51	12,339	149	2.58
	Type II Zones																	
4	Central Bear Creek	64	180	900	14	4.7	.....	.....	.....	2,214	35	2.46	2,558	40	2.84	4,772	75	5.30
7	Little Bear Creek	18	112	560	31	4.7	.....	.....	.....	1,056	59	1.89	883	49	1.58	1,939	108	3.46
11	Upper Second Creek	6	36	180	30	11	52	0	0	1,491	249	8.28	1,698	283	9.43	3,189	532	17.72
	Type III Zones																	
1	Hardin County and Lower Yellow Creek	42	146	730	17	2.4	.....	.....	.....	1,668	40	2.28	509	12	.70	2,177	52	2.98
3	Tishomingo County and Lower Bear Creek	55	94	470	9	2.0	.....	.....	.....	1,785	32	3.80	648	12	1.38	2,433	44	5.18
5	Upper Bear Creek	12	52	260	22	.....	.....	.....	.....	19	2	.07	.....	.....	.....	19	2	.07
6	Colbert County	53	217	1,085	20	0.5	.....	.....	.....	957	18	.88	203	4	.19	1,160	22	1.07
9	Tri-Cities and Reservation	29	4,121	20,605	711	0.4	.....	.....	.....	528	18	.03	616	21	.03	1,144	39	.06
10	Upper Lauderdale County	56	170	850	15	1.8	.....	.....	.....	1,859	33	2.19	134	2	.16	1,993	36	2.34
12	Lower Lauderdale County	61	172	860	14	4.0	.....	.....	.....	791	13	.92	647	11	.75	1,438	24	1.67

[1] Per capita cost relatively low due to urban population in this zone.

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TENNESSEE VALLEY AUTHORITY — HEALTH AND SAFETY DEPARTMENT

WEEKLY REPORT OF INSPECTIONS FOR
MOSQUITO ADULTS AND LARVAE

No. 15

RESERVOIR PICKWICK — WEEK ENDING August 14, '43

STA NO.	ADULT A. QUAD. Total	Fem	Male	ANOPHELES LARVAE Before Treatment No. Dips Tot	Pos.	No. Larv	After Treatment No. Dips Tot	Pos.	No. Larv
				ROUTINE					
	Type I								
5	36	36	0	65	46	232	180	54	151
6	8	8	0	20	16	46	15	0	0
29	4	4	0	325	29	29			
31	8	7	1				125	5	5
32	0	0	0	50	0	0			
35	0	0	0	250	11	14			
36	0	0	0	125	9	9			
	Type II								
17	49	43	6	191	58	259	70	2	3
18	0	0	0	15	10	37	32	0	0
26	3	3	0	100	6	7			
28	0	0	0	150	30	46			
44	2	2	0	60	14	14			
45	0	0	0	80	17	20			
	Type III								
1	1	1	0	20	4	10			
2	0	0	0						
3	1	1	0						
11	1	1	0	20	8	40			
12	0	0	0	10	4	20			
13	0	0	0	15	5	21			
20	1	0	1	35	24	85			
23	0	0	0						
25	0	0	0						
34	0	0	0	175	14	17			
38	1	1	0						
41	2	2	0				20	3	4
43	0	0	0				40	7	8
47	9	9	0	15	6	26			
48	0	0	0	5	4	7			
	Reservoir Totals & Averages								
28	126	118	8		Week Total				
	4.5	4.2	0.3		Week Average				
420	2670	2454	216		Season Total				
	6.4	5.8	0.5		Season Average				

STA NO.	ADULT A. QUAD. Total	Fem	Male	ANOPHELES LARVAE Before Treatment No. Dips Tot	Pos.	No. Larv	After Treatment No. Dips Tot	Pos.	No. Larv
				SUPPLEMENTARY					
4				30	13	27			
7				40	28	111			
14				53	15	97			
19				30	11	32			
22							20	4	5
	Bridge Near Station #25								
	8	5	3						
	Bridge Near Station #28								
	12	10	2						

FIGURE 139.—Form for weekly reporting of inspection for mosquito adults and larvae.

XI. MALARIA MOSQUITOES

In the entire world, there are well over 200 species of anopheline mosquitoes, all of which are probably capable of transmitting malaria under experimental conditions. Fortunately, the really potent vectors are few and usually only one or two species are important in any locality. Biting habits and other specific biological characteristics apparently prevent the other anophelines from transmitting the disease to a significant extent.

In the United States there are 13 species of *Anopheles* mosquitoes, all of which have proved capable of transmitting malaria under experimental conditions. However, epidemiological evidence indicates that only two species, *Anopheles quadrimaculatus* in the East and Southeast and *A. freeborni* in the West, are important as vectors of malaria in this country. A third species, *A. albimanus,* which is the most important transmitter of malaria in the Caribbean area, also occurs in the lower Rio Grande Valley of Texas where it may be of importance. The distribution of these three malaria vectors is shown in figure 140. A list of the more important malaria transmitting mosquitoes of the world, together with a summary of their characteristics and breeding habits, is given in appendix G.

GENERAL CHARACTERISTICS OF MOSQUITOES

In order to evaluate the relative merits of and need for the various antimalaria procedures previously discussed, it is essential that one have a thorough working knowledge of the general characteristics, life cycle, and habits of mosquitoes. The importance of such information is emphasized when it is realized that all mosquito control measures, regardless of their nature or magnitude, are directed against some habit or vital requirement of the *Anopheles* mosquito.

Mosquitoes are small, soft-bodied, two-winged insects belonging to the order Diptera, the family Culicidae, and the subfamily Culicinae. They are distinguished from other insects by the characteristic arrangement of the wing veins, the presence of a proboscis or elongated beak, and scales on the wings, legs, and other parts of the body. Sometimes mosquitoes are confused with crane flies and midges which they superficially resemble. However, close observations will show that these insects do not have scales or fringes on the wings and seldom have long beaks.

Mosquitoes have four stages in their life cycle—the egg; the larva, commonly called a wriggler or wiggletail; the pupa or tumbler; and

FIGURE 140—Distribution of malaria-carrying mosquitoes in the United States.

the adult winged insect or imago (fig. 141). The eggs are laid in batches of 50 to 300 with several batches being laid by one female during her lifetime.

For most species of mosquitoes the female usually must obtain a blood meal before she can produce eggs. Some species of mosquitoes lay their eggs on the water surface; others deposit them on moist

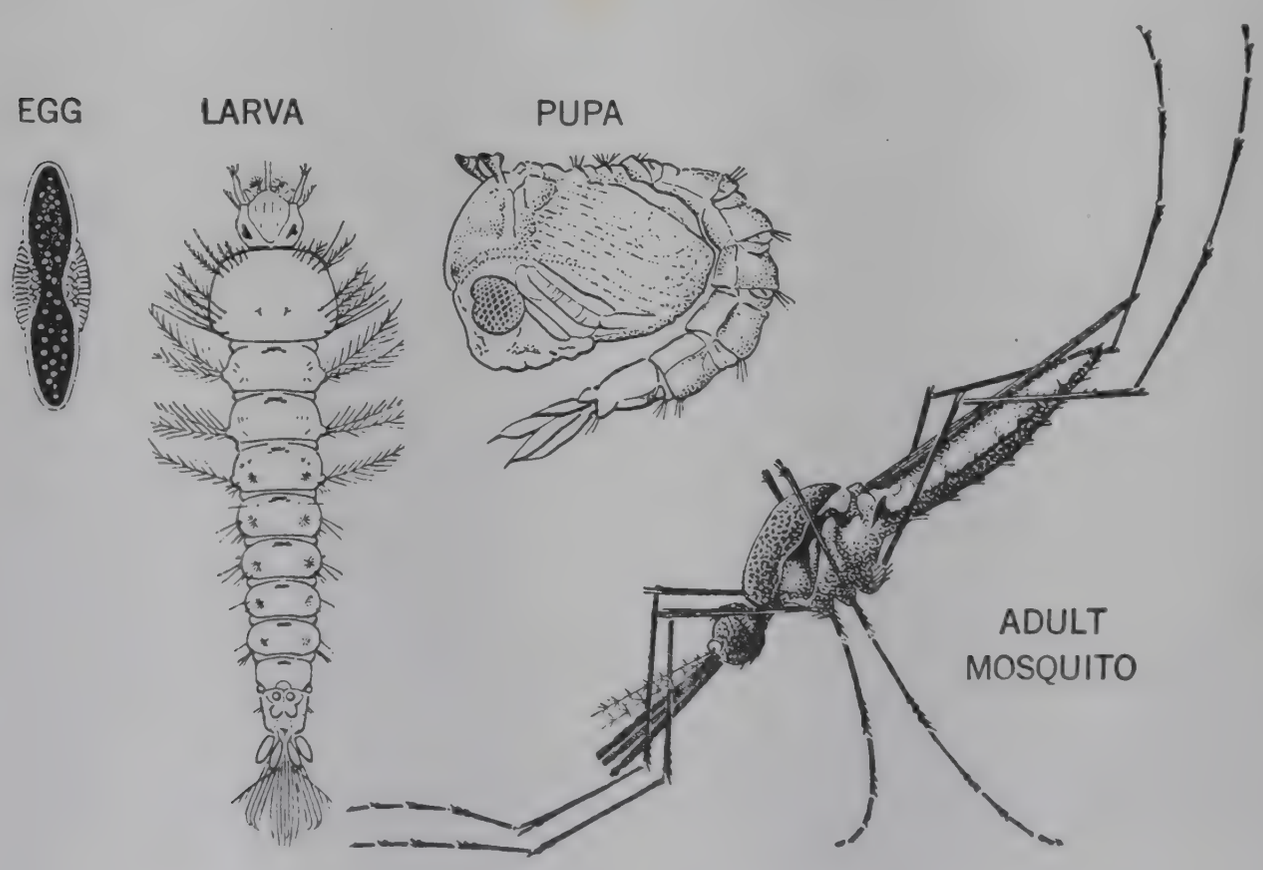


FIGURE 141.—Life cycle of *A. quadrimaculatus*.

ground or other surfaces near the water where they subsequently will be flooded by rising water levels occasioned by rains or tides. When ovipositing, some species glue the eggs together into a raft or boat-shaped mass which floats on the water; others deposit them singly. The period required for eggs to hatch may vary from a few days to several months depending on the species. The larvae hatch from the eggs. Larvae of all mosquitoes are aquatic and most of them are free swimming. Mosquito larvae with few exceptions must come to the surface of the water for air which they breathe through an elongated air tube or other modified apparatus which pierces the surface film. They feed on minute plants and animals and fragments of organic debris which are strained from the water by the action of their mouth parts. Mosquito larvae have three distinct body regions—the head, the thorax, and the abdomen—each of which bears hairs or bristles and other structures the number, shape, and size of which may be used for identification purposes. During the larval period, which may last from a minimum of 4 or 5 days to several weeks, depending on the species and season, the larval skin is shed four times, each successive instar showing a progressive increase in size.

With the fourth larval molt the pupa stage is produced. Pupae also are aquatic and remain at the water surface. They obtain air by means of a pair of breathing tubes or trumpets, located near the head, which are thrust through the water surface. During the pupa stage no feeding takes place. It is a period of marked transformation during which the adult insect is formed from larval tissues. This stage lasts from 2 to several days. When the adult mosquito is fully formed, the pupal skin splits down the back, and the adult mosquito emerges. It rests for a few minutes on the water surface to dry its wings and then flies off to mate and feed. Within a few days a female is ready to deposit her eggs for the start of a new generation.

Some mosquitoes, particularly those which breed in relatively permanent water, have several generations each year, the number depending upon water temperatures and the length of the summer season. Others which breed in temporary rain pools appear each time their breeding places are flooded for a sufficient period of time; while still others, such as the early spring *Aedes,* produce but one brood each year.

Some mosquitoes bite at all hours of the day and night; others, such as the anophelines, are principally night biters; while still others, such as *Aedes aegypti,* the yellow fever mosquito, usually bite in the daytime. Only female mosquitoes suck blood; the males feed on plant nectar or other sweet or fermenting substances, Although the females of most species feed on warm-blooded animals, others

select cold-blooded forms, such as frogs, snakes, etc. The length of life of adult mosquitoes in nature is difficult to determine, but for most of the southern species it apparently is only a few weeks during the summer months. Some of the northern *Aedes* that emerge early in the spring may persist in abundance until midsummer or later. Daily observations of abundance following the emergence of large broods of *Anopheles* and *Aedes* during the summer usually indicate a marked reduction in numbers in about 2 or 3 weeks. The southern house mosquito, *Culex quinquefasciatus,* probably lives longer than this, and the yellow fever mosquito may live an average of a month or more with a maximum of several months. In northern latitudes the females of *Culex* and *Anopheles* usually hibernate, but in the South hibernation of these species is not continuous as the females become active during the warmer periods and larvae may appear in the breeding places.

DIFFERENTIATION BETWEEN ANOPHELINE AND CULICINE MOSQUITOES

The subfamily Culicinae is divided into five tribes. The *Anopheles* or malaria-carrying mosquitoes belong to the tribe Anophelini which includes only the genus *Anopheles* in the United States. All other tribes of mosquitoes usually are referred to as nonanophelines or "culicines" by malaria control workers, although the latter term is not strictly applicable. Anophelines may be separated from all other mosquitoes in their several stages by the characters listed in table 33 and shown in figure 142.

TABLE 33.—*Differentiation of Anopheline and Culicine mosquitoes.*

Stage	Anophelines	Culicines (broad sense)
Adult.....	Palpi of both male and female long, in former clubbed at tip, in the latter about as long as proboscis. Posterior margin of scutellum evenly rounded. Wings usually spotted with a definite color pattern.	Palpi of female much shorter than proboscis. Palpi of male long or short, but never clubbed at the tip. Scutellum posteriorly trilobed. Wings usually clear or without definite color pattern.
Egg.....	More or less boat-shaped with lateral floats; laid singly.	Elongate, ellipsoidal or conical, without lateral floats; laid singly or in rafts.
Larva.....	Horizontal position in the water just below the surface film, with which it maintains contact by palmate hairs and spiracles. Elongate air tube absent.	Maintains contact with the surface film only by the air tube; the body hangs obliquely or vertically downward. Air tube usually well-developed and elongated.
Pupa.....	Air tubes short and widely flared, split down the front.	Air tubes broadly conical or elongate, tubular, unsplit.

ANOPHELINE MOSQUITOES

As stated previously, there are 13 species of *Anopheles* mosquitoes in the United States. These are as follows:

A. quadrimaculatus
A. freeborni
A. occidentalis
A. punctipennis
A. pseudopunctipennis
A. franciscanus

A. walkeri
A. atropos
A. barberi
A. crucians
A. bradleyi
A. georgianus
A. albimanus

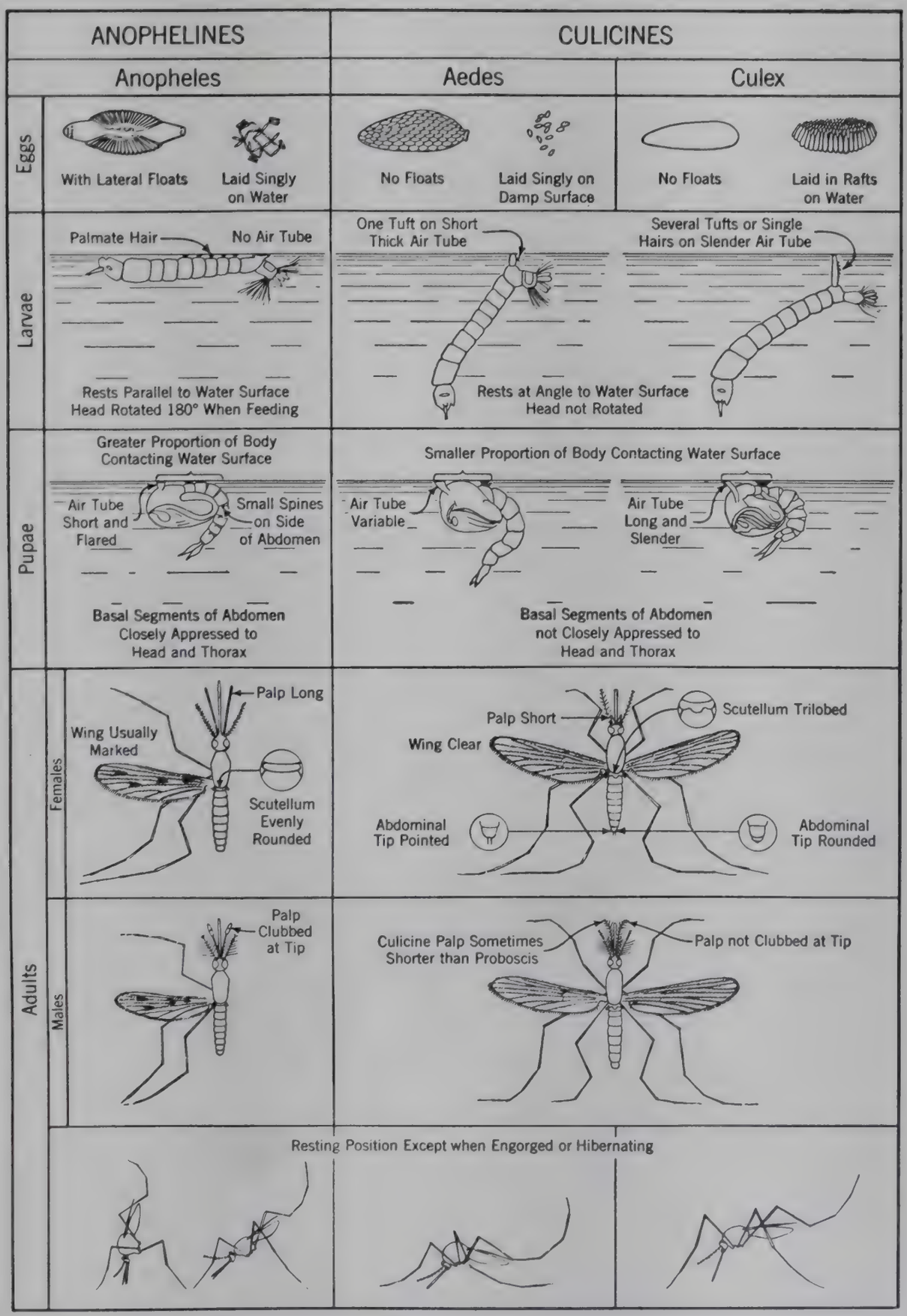


FIGURE 142.—Differentiation of anopheline and culicine mosquitoes.

FIGURE 143.—*Anopheles quadrimaculatus. (A. freeborni* identical.)

FIGURE 144.—*Anopheles albimanus.*

FIGURE 145.—*Anopheles punctipennis.*

FIGURE 146.—*Anopheles crucians* (appearance of *A. bradleyi* and *A. georgianus* indistinguishable from *A. crucians*).

FIGURE 147.—*Anopheles pseudopunctipennis* (*A. franciscanus* identical except palpi are tipped with black).

FIGURE 148.—*Anopheles atropos.*

FIGURE 149.—*Anopheles walkeri*.

FIGURE 150.—*Anopheles barberi*.

FIGURE 151.—*Anopheles occidentalis.*

The identification of anophelines is essential for the malaria control worker in order that he may recognize the species present in his locality and direct his efforts against those which are important in transmitting malaria. Identification requires some knowledge of mosquito anatomy on the part of the field worker, as the distinguishing characters which must be recognized consist of variations, frequently very slight, in the size, shape, coloration or scaling of certain specific parts of the mosquito body. In the pictorial key to adult female anophelines of the United States (fig. 152) a diagrammatic illustration of an adult mosquito is shown on which the principal body structures utilized in identification are named. The variations in these characters among the several United States anophelines are used to separate individual species. The species are first divided into two groups, viz, those having wings with uniformly dark scales and those having wings with both dark and light scales. Each of these groups is then further divided on the basis of other single or combinations of characters. These figured characters illustrate typical conditions which vary with individual specimens in any locality, and in some areas variation from the type may be the rule. For example, the four spots on the wings of *A. walkeri* may vary in intensity from the dark spots typical of *A. quadrimaculatus* to very

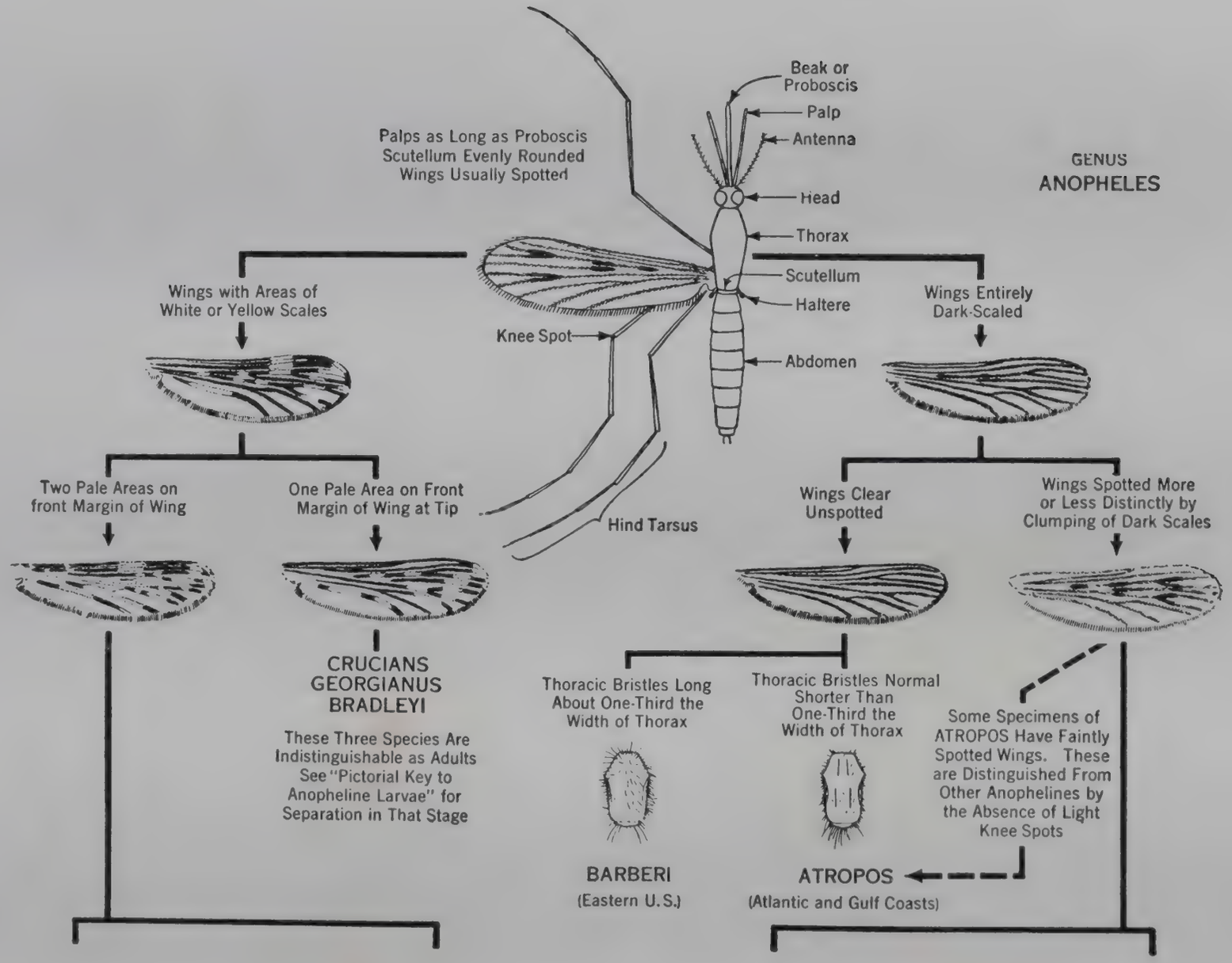
faint spotting approaching that found on typical *A. atropos.* Males generally resemble the females in markings although colorational characters usually are much fainter. The adults of *A. freeborni* and *A. quadrimaculatus* cannot be distinguished by coloration characters alone, and positive identification must be based upon the structure of the terminal abdominal segments of the male (genital and anal parts) or upon the larvae. The study of terminalia involves the use of delicate techniques which are not practical for the field worker or for those without special training. The three species of the *A. crucians* complex—*A. crucians, A. bradleyi,* and *A. georgianus*—also cannot be determined by coloration characters nor even by male terminalia with certainty. However, these can be identified readily in the larval stage.

Larval identification is based on certain minute body characters and requires the use of a microscope. Unless this equipment is available, it is not practical to identify larvae in the field or field office. Identifications should be made by rearing the larvae and identifying the adults, or the larvae may be preserved and sent to a specialist for identification. In the pictorial key, figure 153, a diagrammatic illustration of a fourth-instar anopheline larva is given with the various characters labeled which are used in identification of various species. Only mature larvae should be used for identification purposes since the characters of earlier instars are unreliable for this key.

The abundance of each species varies greatly in the different parts of its range depending upon the availability and extent of suitable breeding places and probably upon the length of the season during which suitable temperatures occur. In the case of *Anopheles punctipennis,* the most widely spread species in the United States, higher densities occur more frequently in the North than in the South; densities of *A. quadrimaculatus,* the most common southern anopheline, are often as great in some northern localities as in the South in spite of the shorter season.

The known geographical distribution of the species should always be considered in making preliminary identification of either adults or larvae. Species should not be reported as occurring in localities beyond their known range unless positive identification has been made by specialists.

The eggs of anophelines can be separated by minute structural characters. However, since the eggs rarely are encountered by the field worker, it is unnecessary for him to attempt identification. Also, the separation of anopheline pupae is somewhat difficult and unreliable, and since this stage lasts but 2 or 3 days, pupae should be reared and identification made of adults.


Beak or Proboscis
Palp
Antenna
Head
Thorax
Scutellum
Haltere
Abdomen
Knee Spot
Hind Tarsus
Palps as Long as Proboscis
Scutellum Evenly Rounded
Wings Usually Spotted
GENUS
ANOPHELES
Wings with Areas of White or Yellow Scales
Wings Entirely Dark-Scaled
Two Pale Areas on front Margin of Wing
One Pale Area on Front Margin of Wing at Tip
Wings Clear Unspotted
Wings Spotted More or Less Distinctly by Clumping of Dark Scales
CRUCIANS
GEORGIANUS
BRADLEYI
These Three Species Are Indistinguishable as Adults See "Pictorial Key to Anopheline Larvae" for Separation in That Stage
Thoracic Bristles Long About One-Third the Width of Thorax
Thoracic Bristles Normal Shorter Than One-Third the Width of Thorax
Some Specimens of ATROPOS Have Faintly Spotted Wings. These are Distinguished From Other Anophelines by the Absence of Light Knee Spots
BARBERI
(Eastern U.S.)
ATROPOS
(Atlantic and Gulf Coasts)

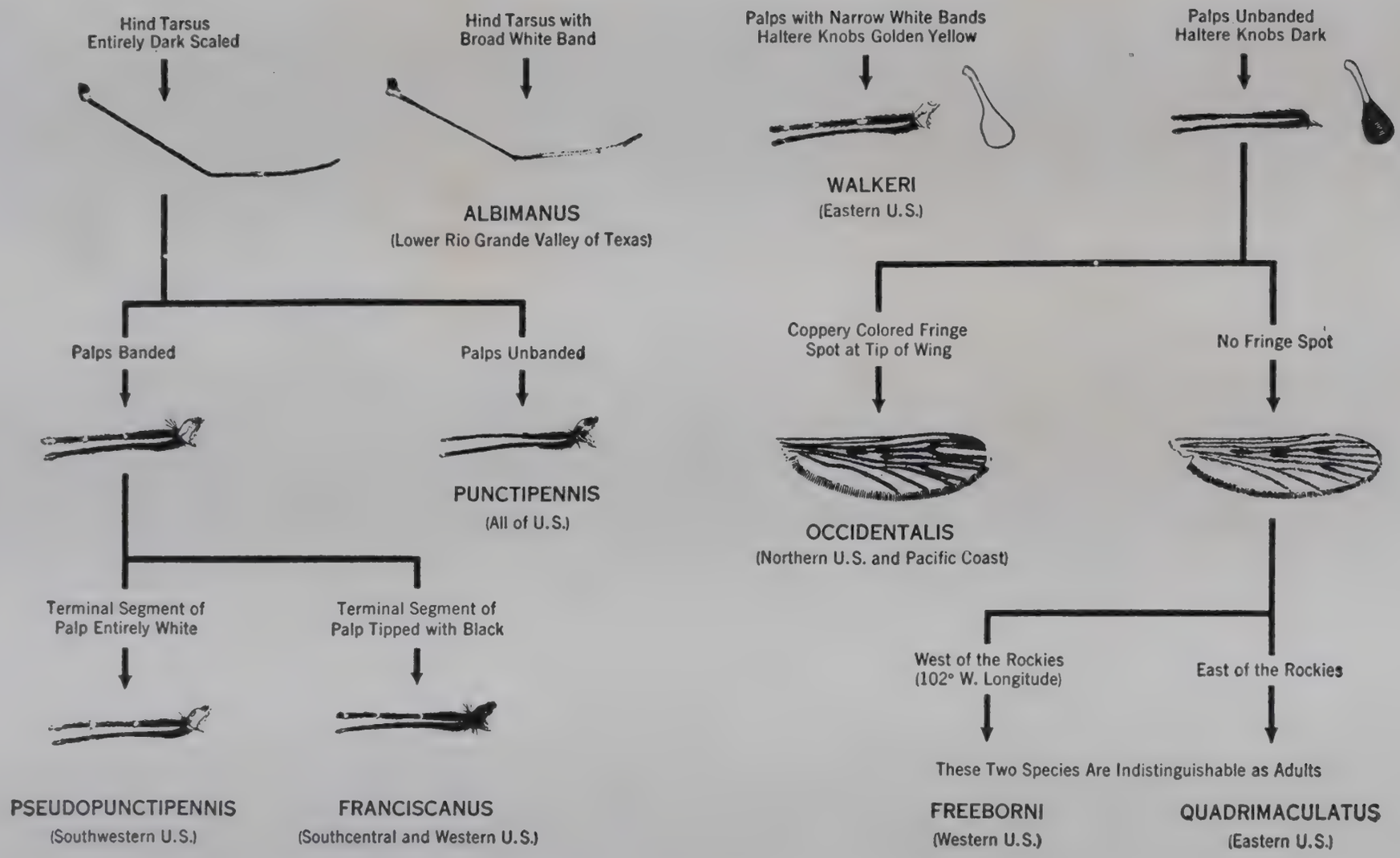
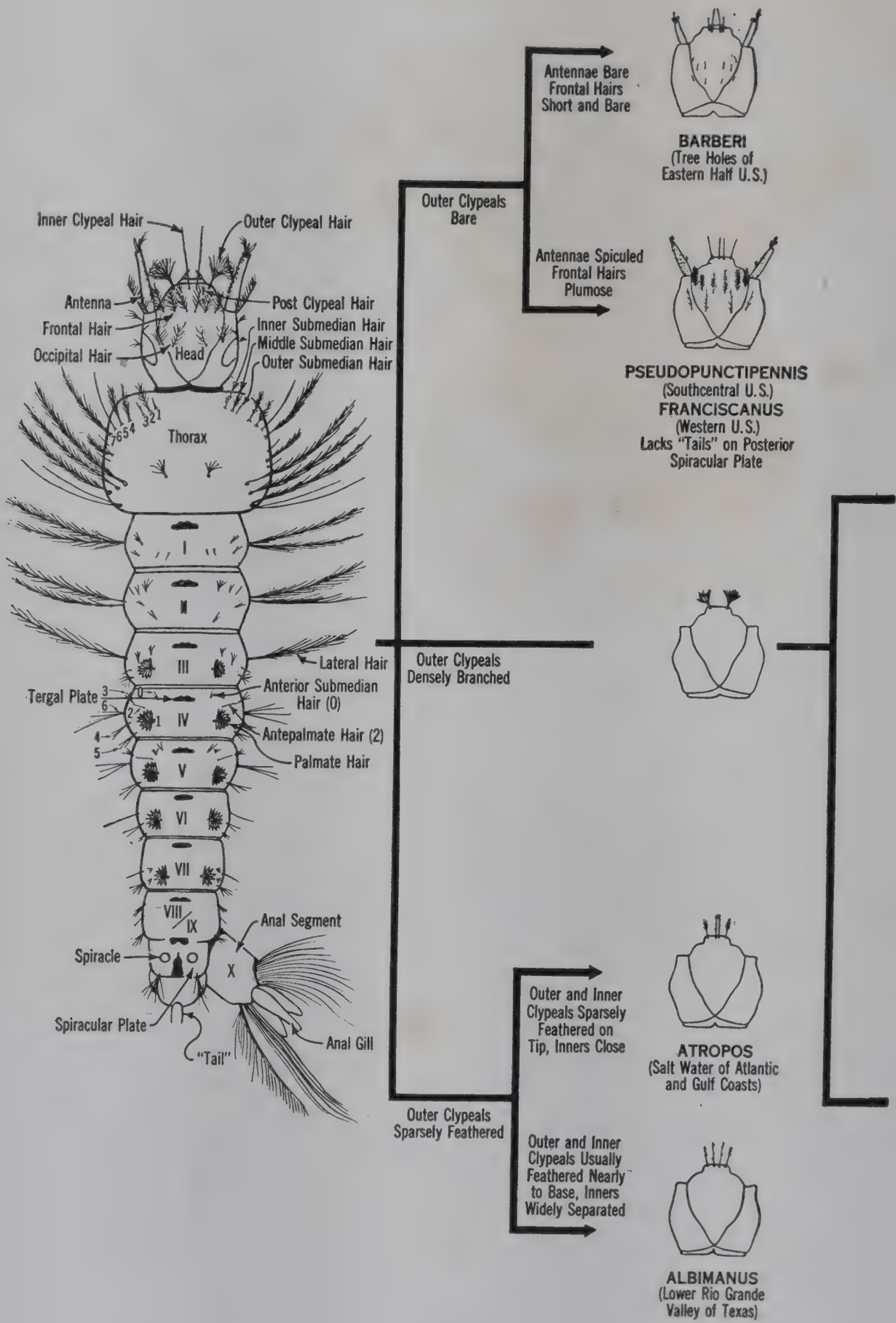


FIGURE 152.—Pictorial key to adult anopheline mosquitoes in the United States.


Inner Clypeal Hair
Outer Clypeal Hair
Antenna
Frontal Hair
Occipital Hair
Head
Post Clypeal Hair
Inner Submedian Hair
Middle Submedian Hair
Outer Submedian Hair
Thorax
Lateral Hair
Tergal Plate
Anterior Submedian Hair (0)
Antepalmate Hair (2)
Palmate Hair
Anal Segment
Spiracle
Spiracular Plate
"Tail"
Anal Gill
Outer Clypeals Bare
Antennae Bare
Frontal Hairs Short and Bare
BARBERI
(Tree Holes of Eastern Half U.S.)
Antennae Spiculed
Frontal Hairs Plumose
PSEUDOPUNCTIPENNIS
(Southcentral U.S.)
FRANCISCANUS
(Western U.S.)
Lacks "Tails" on Posterior Spiracular Plate
Outer Clypeals Densely Branched
Outer Clypeals Sparsely Feathered
Outer and Inner Clypeals Sparsely Feathered on Tip, Inners Close
ATROPOS
(Salt Water of Atlantic and Gulf Coasts)
Outer and Inner Clypeals Usually Feathered Nearly to Base, Inners Widely Separated
ALBIMANUS
(Lower Rio Grande Valley of Texas)

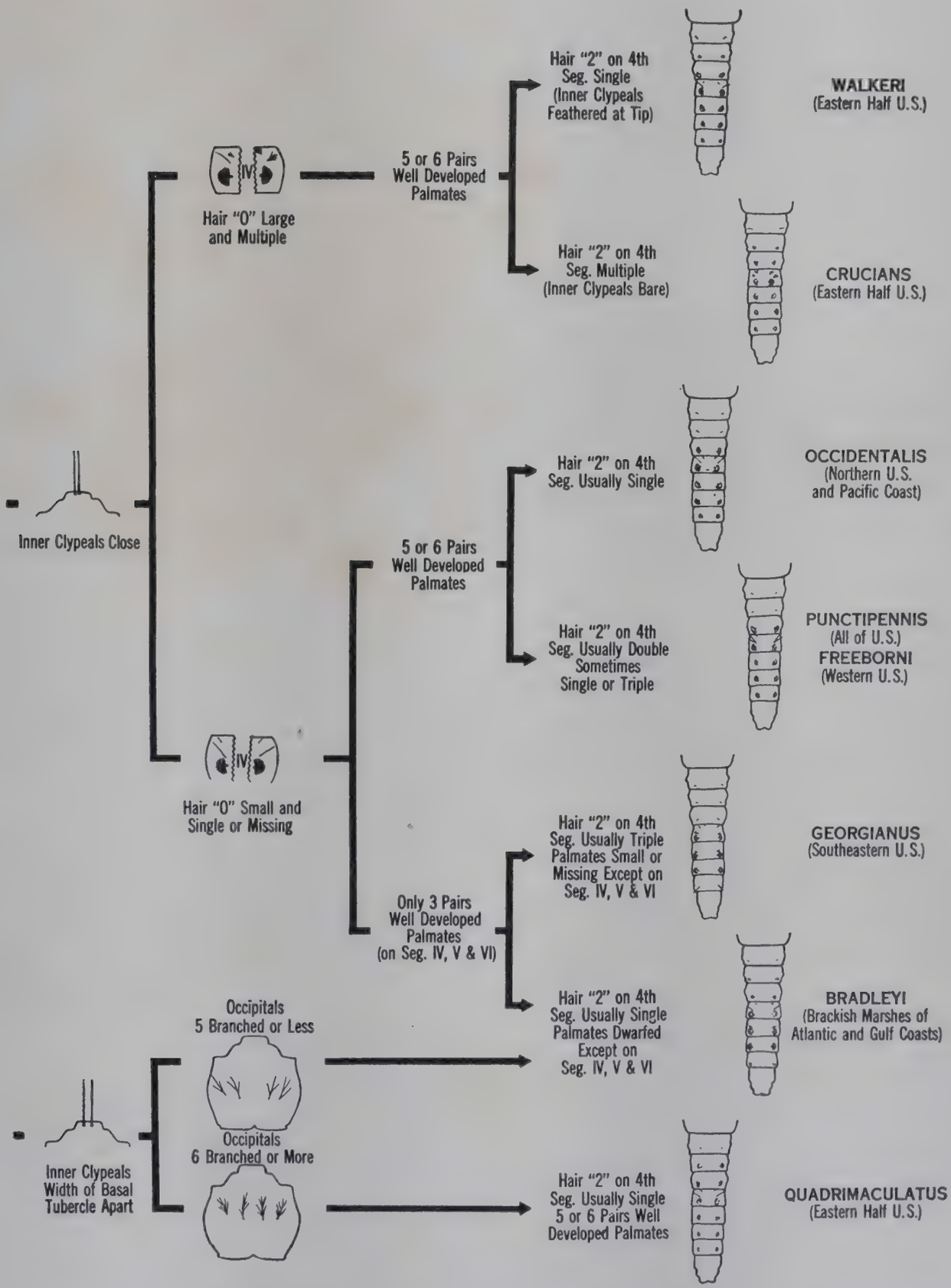

Inner Clypeals Close
Hair "0" Large and Multiple
5 or 6 Pairs Well Developed Palmates
Hair "2" on 4th Seg. Single (Inner Clypeals Feathered at Tip)
WALKERI (Eastern Half U.S.)
Hair "2" on 4th Seg. Multiple (Inner Clypeals Bare)
CRUCIANS (Eastern Half U.S.)
Hair "0" Small and Single or Missing
5 or 6 Pairs Well Developed Palmates
Hair "2" on 4th Seg. Usually Single
OCCIDENTALIS (Northern U.S. and Pacific Coast)
Hair "2" on 4th Seg. Usually Double Sometimes Single or Triple
PUNCTIPENNIS (All of U.S.) FREEBORNI (Western U.S.)
Only 3 Pairs Well Developed Palmates (on Seg. IV, V & VI)
Hair "2" on 4th Seg. Usually Triple Palmates Small or Missing Except on Seg. IV, V & VI
GEORGIANUS (Southeastern U.S.)
Hair "2" on 4th Seg. Usually Single Palmates Dwarfed Except on Seg. IV, V & VI
BRADLEYI (Brackish Marshes of Atlantic and Gulf Coasts)
Inner Clypeals Width of Basal Tubercle Apart
Occipitals 5 Branched or Less
Occipitals 6 Branched or More
Hair "2" on 4th Seg. Usually Single 5 or 6 Pairs Well Developed Palmates
QUADRIMACULATUS (Eastern Half U.S.)

FIGURE 153.—Pictorial key to anopheline larvae of the United States.

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BIOLOGY OF ANOPHELINE MOSQUITOES

Anopheles quadrimaculatus

A. quadrimaculatus adults are dark brown mosquitoes having more or less distinct dark spots on each wing, and unbanded palpi and legs. In size and wing markings this species closely resembles *A. freeborni, A. occidentalis,* and *A. walkeri.* Occasional specimens of *A. atropos* may also have faint wing markings similar to *A. quadrimaculatus.* On colorational characters adults of *A. freeborni* are indistinguishable from *A. quadrimaculatus* (fig. 143).

A. quadrimaculatus mosquitoes usually breed in fresh, clear, quiet, slightly acid to alkaline bodies of warm water of a more or less permanent nature which contain an abundance of vegetation or floating material. Common habitats include lime-sink ponds, river flood plains, sloughs, bayous, and the shallow margins and backwater areas of reservoirs (fig. 154). In these situations the number of mosquitoes produced is usually correlated with the extent of intersection of plants and floating material with the water surface. This "intersection line" appears to be the dominant factor in determining the numbers of *A. quadrimaculatus* which will be produced in most natural breeding places. In situations where there is an abundance of intersection line, adult mosquitoes find ideal conditions for oviposition and larvae are provided with ample food and protection from predators and wave action.

Larvae of *A. quadrimaculatus* feed almost entirely at the water surface and show little preference, eating anything small enough to be ingested. Green algae, diatoms, and flagellated protozoans are usually abundant in water where *A. quadrimaculatus* are breeding. These organisms make up the bulk of the food of the larvae.

Water temperatures are important in relation to the production and rate of development of *A. quadrimaculatus.* Although the immature stages will withstand low water temperatures and may even survive being frozen in solid ice, completion of development to the adult stage does not usually take place at temperatures below 50° to 55° F. No appreciable development takes place until the water surface has reached 65° to 70° F. Optimum development appears to take place when the water temperature is between 85° and 90° F. Although larvae may frequently be collected where the afternoon water surface temperature is well above 100° F., they probably cannot survive constant water temperatures much above 95° F. An illustration of the relative effects of water surface temperature upon production of *A. quadrimaculatus* and *A. punctipennis* larvae is given in figure 155. Under optimum conditions during the middle of the summer, development from egg to adult may be completed in

as short a period as 8 or 9 days, but usually requires about 2 weeks (fig. 156) ; during the spring and fall when water surface temperatures average between 60° and 70° F., a month or longer may be required to complete development.

Breeding of *A. quadrimaculatus* is usually more intense in low vegetation open to sunlight than in densely shaded areas. Shade inhibits the growth of phytoplankton and the higher aquatic plants, thus limiting the amount of food and protection provided for the larvae. However, considerable production of *A. quadrimaculatus* may occur even in heavily wooded areas, the larvae usually being found in association with flotage comprised of twigs, bark, leaves, and other materials which have fallen from the trees.

A. quadrimaculatus prefers neutral to alkaline waters and does not usually occur when the pH is lower than 6.0. An abundant population of desmids frequently characterizes waters that are too acid for *A. quadrimaculatus* production. Breeding seldom occurs in stagnant waters heavily polluted with plant or animal matter. Such waters usually have a low oxygen content and a high carbon dioxide content and frequently exhibit a heavy waterbloom of *Euglena.*

The immature stages of *A. quadrimaculatus* are preyed upon by many different kinds of aquatic organisms. Of particular importance in this respect are fish, such as the top minnow, *Gambusia affinis affinis,* and predaceous aquatic insects, such as dragonfly nymphs, beetle larvae, and several kinds of water bugs. Although these

FIGURE 154.—Typical habitat of *A. quadrimaculatus* in a reservoir.

natural predators are very helpful in limiting the production of *A. quadrimaculatus*, they cannot in themselves be relied upon to provide adequate control except possibly in special situations, such as in small ponds heavily stocked with *Gambusia* and relatively free of vegetation and flotage.

As with all mosquitoes, *A. quadrimaculatus* does not feed during the pupal stage. At the time of emergence the pupal skin splits along the back, and the adult mosquito withdraws itself and rests upon the water surface for a short period until its wings are dry. Mating may take place during the first day after emergence and may occur either before or after the first blood meal is taken. Mating is frequently observed in the evening about sundown during swarming of the males. Although a female may mate repeatedly, one insemination is sufficient to insure the production of viable eggs during her entire life span.

Oviposition usually occurs 2 to 3 days following the taking of a blood meal, and the eggs are deposited singly upon the water surface. The number of eggs deposited at one oviposition is usually 100 to 300. A single female may oviposit as many as 12 times during her life span and lay a total of over 3,000 eggs. Egg laying takes place only at night, and most eggs are probably deposited during the first hour after darkness begins.

During the daytime *A. quadrimaculatus* mosquitoes remain relatively inactive, resting in cool, damp, dark places, such as barns,

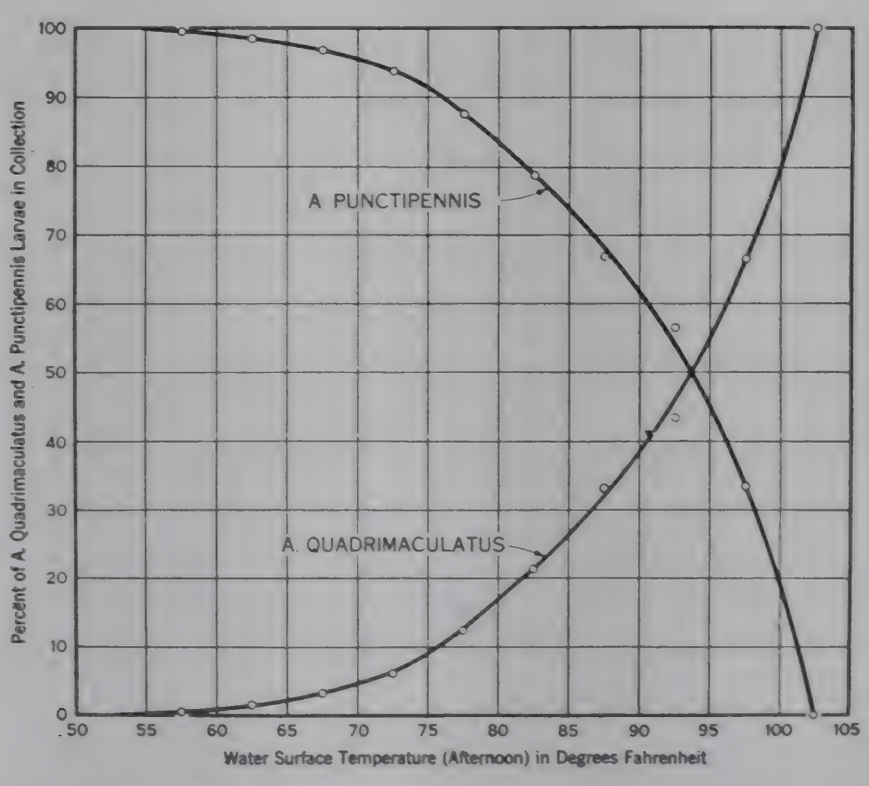

FIGURE 155.—Relative effect of water surface temperature upon production of *A. quadrimaculatus* and *A. punctipennis* in reservoirs of the Tennessee Valley.

caves, hollow trees, and under bridges. The female typically assumes an angle about 45° to the surface when resting or taking a blood meal. Blood meals are taken almost entirely at night although some daytime feeding may occur on dark, cloudy days or in heavily shaded woods. *A. quadrimaculatus* mosquitoes enter houses readily and feed upon humans; however, they also feed extensively on other warm-blooded domestic animals, particularly cows, and to a lesser extent, horses, mules, pigs, chickens, dogs, and cats. Humans are, therefore, probably provided with some degree of protection from being bitten when these animals are available.

The effective flight range of *A. quadrimaculatus* is usually considered to be 1 mile, although reliable records indicate that under unusual conditions a few may fly at least 3 to 4 miles. Normally most of the adults do not fly farther than one-half mile from their breeding place and only a very small percentage fly farther than a mile. (See fig. 157.) Whether or not the small percentage which flies farther than 1 mile is of epidemiological significance depends, of course, upon the total numbers produced and the prevailing malaria parasite rates in the human population. There is some evidence that *A. quadrimaculatus* adults may make prehibernation flights in the

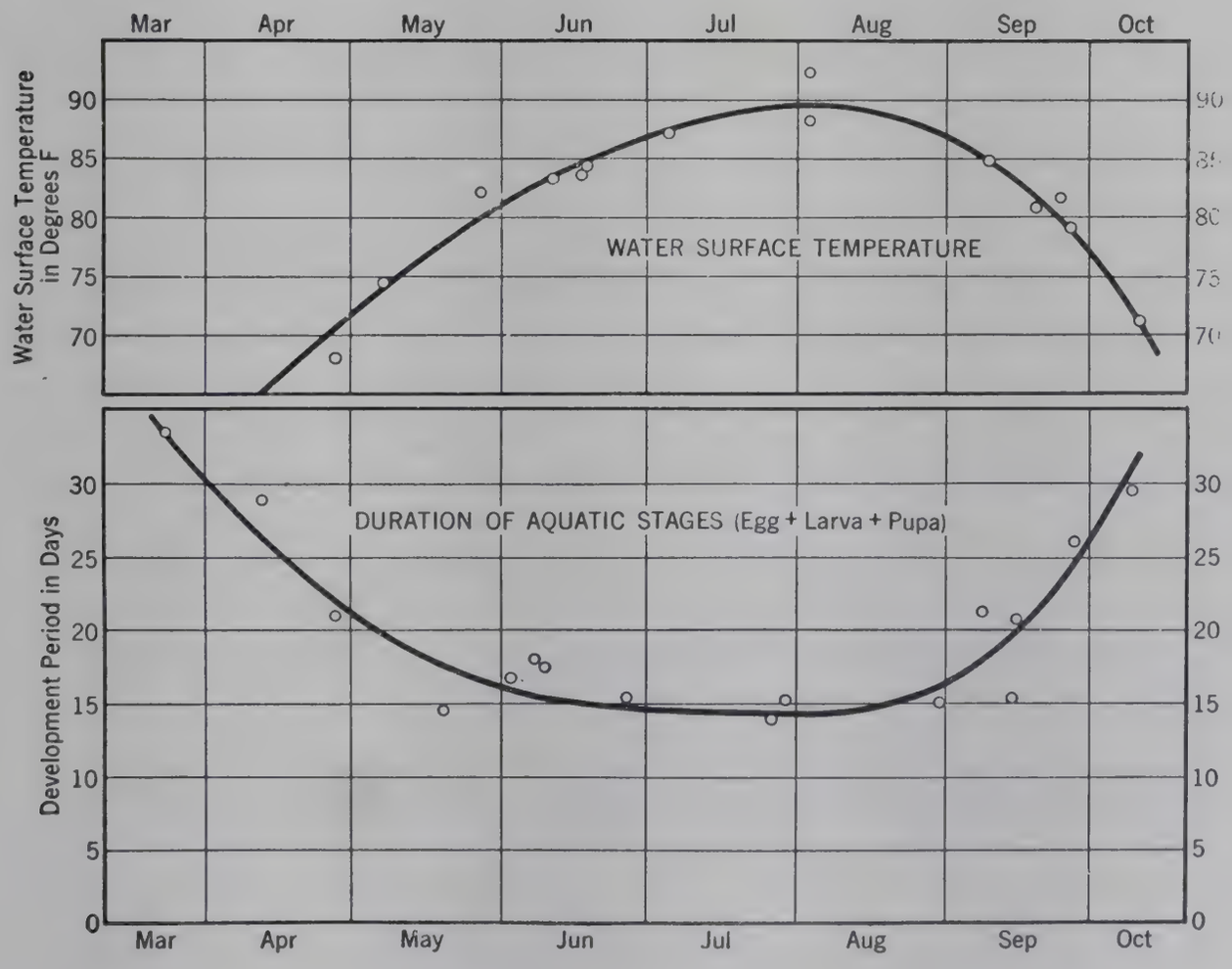

FIGURE 156.—Relation of water temperature to duration of aquatic stages of *A. quadrimaculatus*.

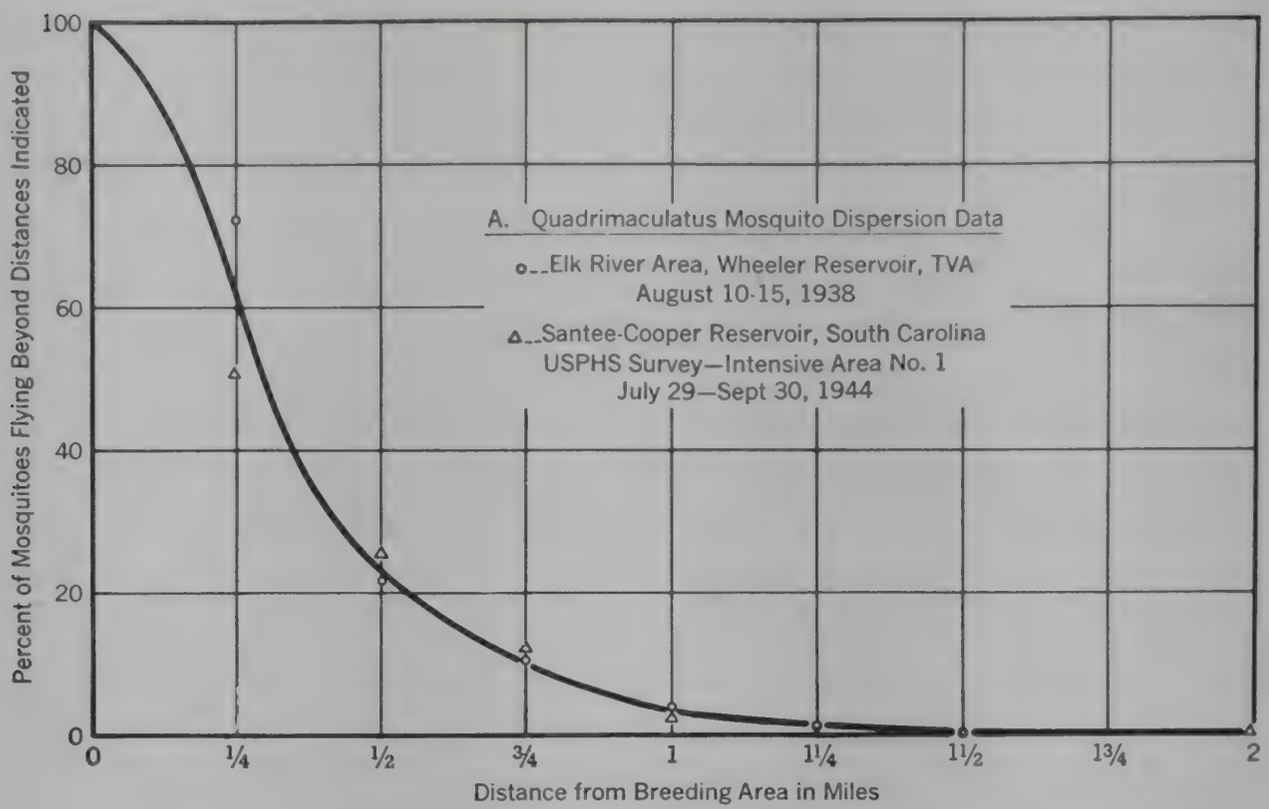

FIGURE 157.—Flight range of *A. quadrimaculatus*.

fall to distances considerably greater than those reached during normal summer flights.

Over most of its range *A. quadrimaculatus* spends the winter as inseminated adult females in caves, hollow trees, cellars, and similar situations where freezing temperatures are not reached. The temperatures in open caves where large numbers of *A. quadrimaculatus* hibernate have been found to remain well above freezing even when outside temperatures reach 10° to 20° F. below freezing. In the most southerly part of its range, this mosquito may breed continuously throughout the year. Even as far north as Tennessee females emerge from hibernation to take blood meals during warm periods in the winter, most such feeding taking place when air temperatures are between 65° and 75° F., but sometimes occurring at temperatures as low as 50° F. In the isothermal zone of 60°–65° F. (see fig. 158), adults usually disappear from their hibernating shelters during February. They take blood meals and probably deposit eggs during March, from which the first brood of adults emerges during April. The first appearance of significant numbers of *A. quadrimaculatus* in natural resting places about the middle of May apparently indicates the emergence of the second generation of adults. There may be as many as 9 or 10 generations each season. Populations reach a peak during July and August and then drop off rapidly through September, usually reaching insignificant numbers by October 1. During October adults with well-developed fat bodies begin to appear in caves and other places of hibernation, maximum numbers being found

during November. The seasons of significant *A. quadrimaculatus* production in various isothermal zones in the southeastern United States are shown in figure 158.

Temperatures determine to a large extent the longevity of *A. quadrimaculatus* adults, the length of life being considerably extended during periods of low temperature. High humidities also favor increased longevity and greater activity of the adults. Hibernating females may survive for 4 or 5 months, and even during the summer breeding season occasional adults may live as long as 2 months. During the cool weather of spring and fall in the Tennessee Valley, the mean survival time of adult females is probably between 3 and 4 weeks, but during the middle of the summer it may be reduced to 2 weeks or less. In some situations, a significant portion of the females may not live long enough during the hot dry midsummer weather to develop sporozoites and transmit malaria. The

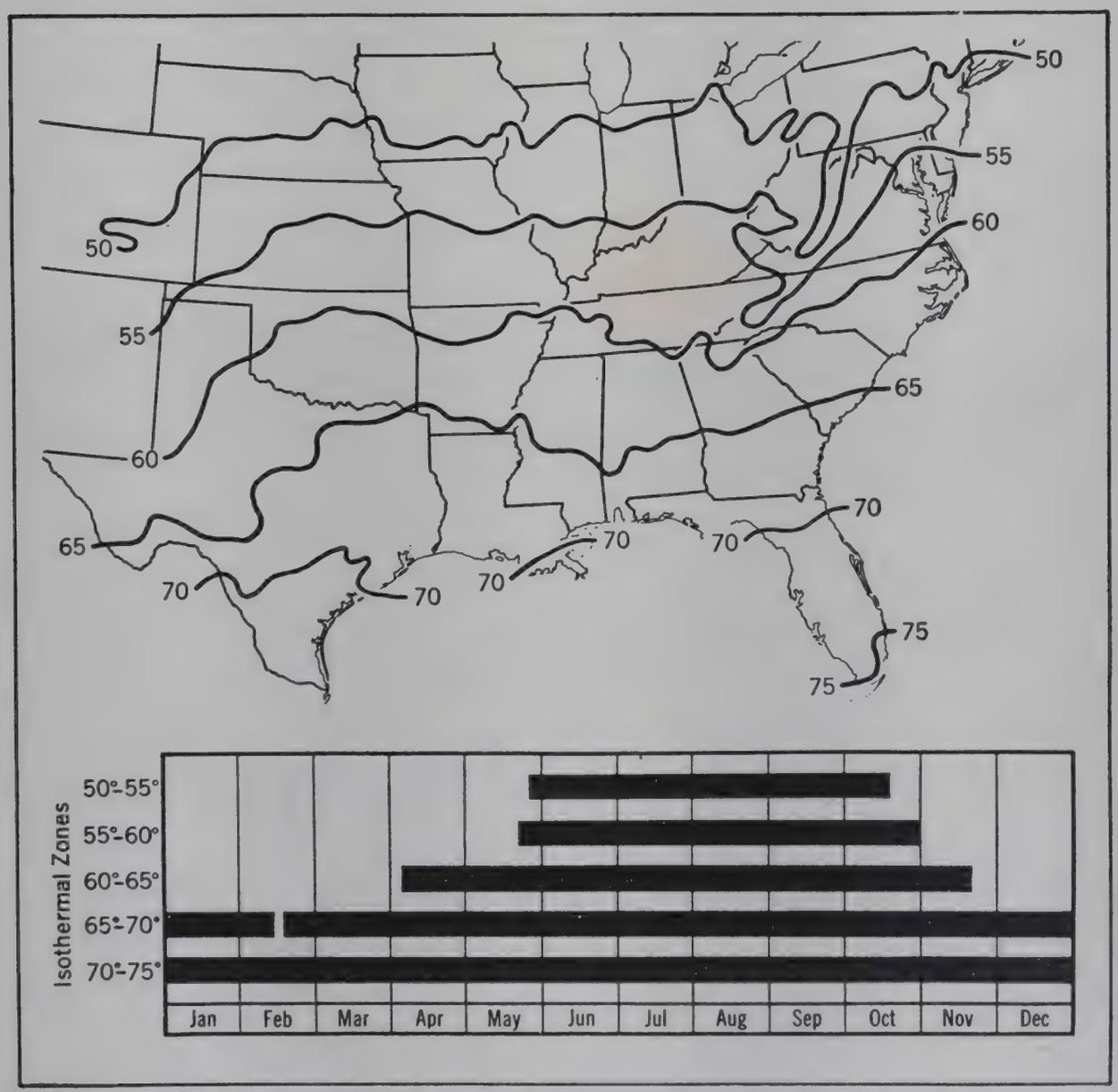

FIGURE 158.—Seasonal duration of significant *A. quadrimaculatus* production in the United States. (Based on maximum weekly station counts of 10 *A. quadrimaculatus,* 1942-44)

males are much shorter lived than the females, the average length of life probably being only about one-third that of the females.

Anopheles freeborni

A. freeborni so closely resembles *A. quadrimaculatus* in appearance that the two are indistinguishable on coloration characters in the adult stage. They may be separated, however, by minute characters of the male terminalia. The larvae are distinguished from those of *A. quadrimaculatus* but cannot be separated from those of *A. punctipennis*. When *A. freeborni* and *A. punctipennis* occur together, adults must be reared for positive identification.

A. freeborni is the principal malaria vector in the western United States. It breeds principally in small pools of comparatively fresh water which are at least partially exposed to sunlight and contain vegetation and flotage. It rarely is found in foul water, artificial water containers, clean bank borrow pits, extensive swamps in heavily wooded areas, or in large deep pools of water. Typical breeding places include bays and streams, ponds, shallow cut-off pools, semipermanent roadside pools resulting from careless irrigation, irrigation canals and ditches, abandoned rice fields, depressions in

FIGURE 159.—Typical breeding habitat of *A. freeborni*.

seepage areas, and countless similar situations. A typical breeding area is shown in figure 159.

A. freeborni is associated with semiarid regions, and its seasonal history and habits are governed by the presence of favorable breeding areas. In California heavy rains occur from November to April or May and produce many suitable breeding areas. A dry season follows which lasts until October or November during which period the breeding places gradually decrease in number. In the late fall females from the last generation disperse from the restricted breeding foci present at that time to resting places near areas which will be favorable for breeding with the coming of the wet season. Here they enter a condition of semihibernation from which, during warm periods, they emerge, become active, and bite. In February they leave their hibernating places, feed voraciously, and soon lay eggs for the first spring generation. Because a majority of breeding places at this time are free of predators, very heavy broods emerge. Succeeding generations, of which about six occur in central California, are greatly reduced in range and size by recession of waters, except where irrigation waters maintain continuous breeding places which otherwise would be dry due to lack of summer rains.

The long dispersal flights of this species necessitate that control anophelines because the last three segments of the hind tarsus are breeding area. This is true especially if densities are high and the size of the control zone can only be determined by the densities occurring in the area. Counts in natural resting places are reliable indices of adult abundance. Because of the hot, dry climate during June, July, and August, adult densities normally are quite low as compared with those encountered earlier and later. This is because the adult mosquitoes live only a short time, perhaps only a few days during this period.

Anopheles albimanus

A. albimanus is readily distinguished from all other United States anophelines because the last three segments of the hind tarsus are almost completely white (fig. 144). It is a tropical species, and in the United States it occurs only in the lower Rio Grande Valley of Texas. Although it is the most important carrier of malaria in the Caribbean region, its importance in this respect in the United States has not been fully determined.

A. albimanus breeds in a wide variety of situations in both fresh and brackish water. It occurs in permanent or semipermanent pools, swamps, marshes, ponds, and along margins of relatively fast-moving streams. As with other *Anopheles* an abundance of vegetation or

floating debris is necessary for its existence in large bodies of water where wave action or predators otherwise would inhibit breeding. Large numbers of *A. albimanus* larvae frequently are found in small ground pools, such as hoofprints, wheel ruts, seepage pools, and artificial containers, especially if these are in full sunlight and algae are present. Breeding of this species can be eliminated by increasing the relative salinity to about 75 percent sea water.

Observations indicate the normal flight range of *A. albimanus* to be approximately 2 miles, but occasionally it has been necessary to establish a control zone from 2½ to 3 miles from the breeding area.

The daytime resting places of *A. albimanus* in the lower Rio Grande valley are similar to those of *A. quadrimaculatus*. However, in the West Indies and Panama *A. albimanus* does not inhabit such daytime resting places to any extent, and the use of animal-baited traps or light traps is necessary for obtaining density indices. *A. albimanus* is readily attracted to light, and recent studies in Puerto Rico have shown that light trap records indicate densities and fluctuations in population more reliably than do the animal traps.

Anopheles punctipennis

A. punctipennis is recognized by the two yellowish spots on the fore margin of the wing, unmarked palpi, and a wide gray longitudinal stripe on the mesonotum (fig. 145). This species ranges throughout most of the breadth of the United States from the Atlantic to the Pacific (fig. 160). It is our most widely distributed anopheline, and it is found in all except the more arid regions. It breeds in a wide variety of habitats, but appears partial to the grassy edges of slow flowing streams. It prefers cooler water than does *A. quadrimaculatus* (fig. 143). This is believed to explain its occurrence in greater numbers in the spring and fall in its southern range; farther north a more nearly even seasonal population is encountered.

The natural resting places of *A. punctipennis* are similar to those of *A. quadrimaculatus* although it does not enter houses or other buildings with anywhere near the frequency that *A. quadrimaculatus* or *A. freeborni* do. It often has been termed a "porch biter." Culverts and bridges are perhaps more frequently used by it for daytime resting. *A. punctipennis* also is readily attracted to light traps. When at rest, the axis of the body and beak is almost perpendicular to the surface, and in this respect is intermediate between *A. crucians* and *A. quadrimaculatus*. Although *A. punctipennis* is readily infected with malaria parasites in the laboratory, its habit of seldom entering human habitations probably explains the fact that it has never been shown to be responsible for malaria infections in nature.

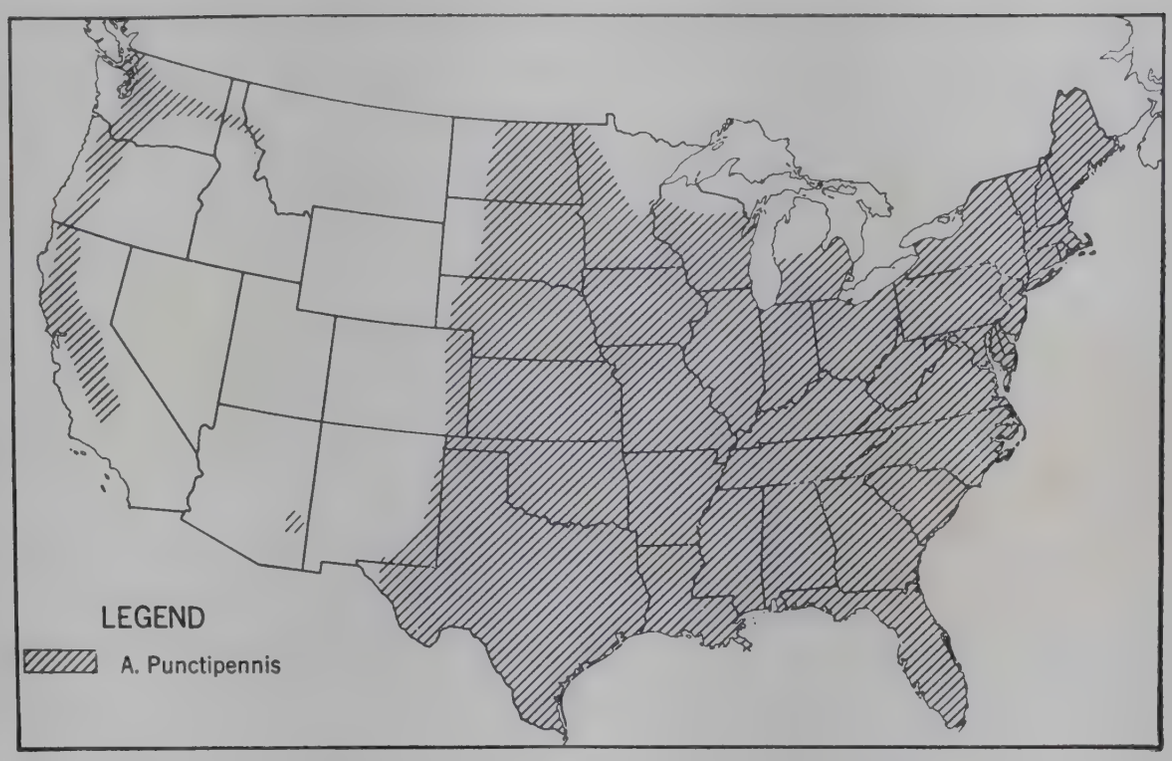

FIGURE 160.—Distribution of *A. punctipennis* in the United States.

Anopheles crucians complex

Anopheles crucians, A. bradleyi, and *A. georgianus,* taken together, constitute what is termed the *"crucians complex"* (fig. 146). The adults of these three species cannot be separted with certainty from one another although their larvae are readily distinguishable. The adults differ from all other United States anophelines in having one white spot at the tip of the wing and three black spots on the anal wing vein.

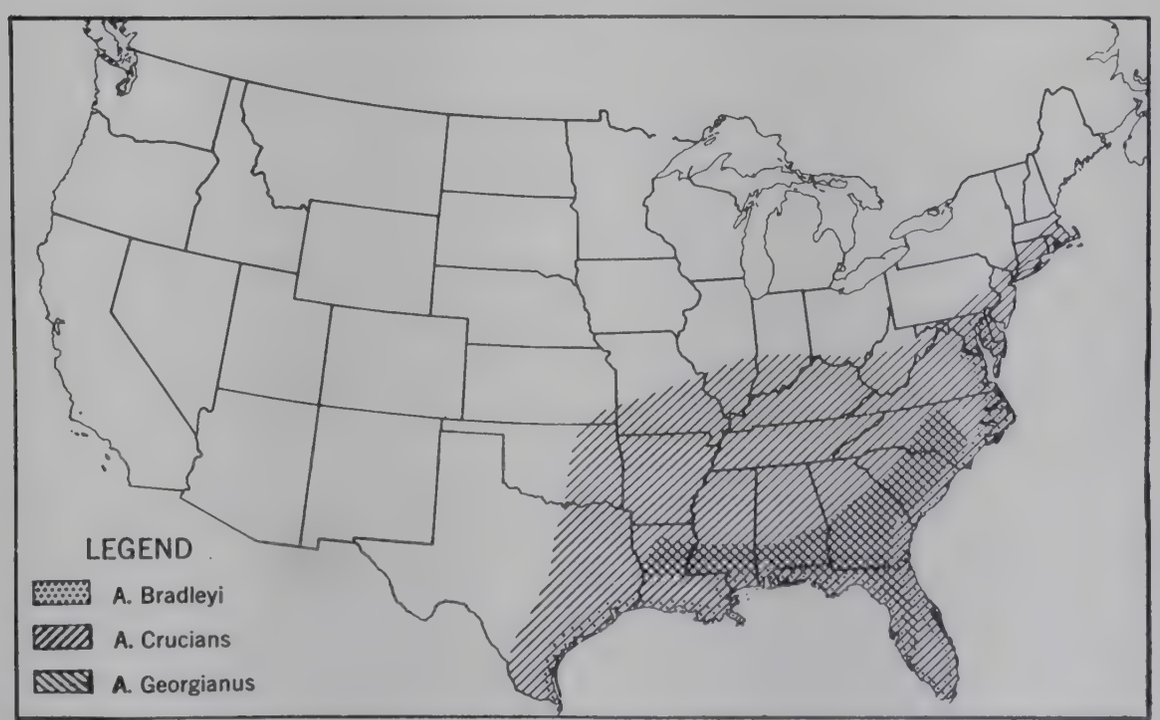

FIGURE 161.—Distribution of *A. bradleyi, A. crucians,* and *A. georgianus* in the United States.

A. crucians is a common species in the low coastal plains of the Southeastern States and has been found as far west as Pecos Valley in New Mexico. Although susceptible to infection with malaria parasites, it rarely has been found infected in nature and is not considered to be of much importance as a malaria carrier. It breeds principally in swamp pools which usually are partly shaded and prefers slightly acid waters. The adults frequent the same type of daytime resting places as *A. quadrimaculatus* and are attracted to light traps in larger numbers. *A. crucians* is distinguished from all other United States anophelines when resting by the angle of the body, which approaches 90° with the resting surface.

A. bradleyi occurs only along the Atlantic and Gulf Coasts from New York to Vera Cruz, Mexico. It breeds in brackish water pools containing flotage, algae, and grasses in and adjacent to the coastal salt marshes. Little is known of the adult habits although these are probably similar to those of *A. crucians*. The adults have been infected experimentally with malaria parasites, but the species is not considered to be of any importance in malaria transmission in nature.

A. georgianus occurs locally in the Southeastern States and has been taken as far west as eastern Texas. The larvae are found in hoofprints, in pastureland seepage areas, in pot holes, and sluggish swamp streams having acid waters. It has been found breeding in association with *A. crucians, A. punctipennis,* and *A. walkeri* in such places. Little is known of adult habits, but presumably they are similar to those of *A. crucians*.

Anopheles pseudopunctipennis

There are two species in the *A. pseudopunctipennis* complex in the United States, *A. pseudopunctipennis* which has the palpi white tipped (see fig. 147) and *A. franciscanus* which has the palpi tipped with black. Both species are otherwise similar in appearance. They are distinguished from all other United States anophelines by the characteristic wing markings which somewhat resemble those of *A. punctipennis;* however, the white-marked palpi readily separate them from that species.

A. pseudopunctipennis occurs in the south central part of the United States where it appears to have a rather localized distribution. It breeds in pools and eddies in shallow or drying streams, especially those containing mats of green algae, and in other ground pools and ponds. It also has been taken in artificial containers such as fountains and tanks. The larvae apparently require a sunlit habitat and rarely occur in shady situations. The habits of the adults are

not well established. In some areas it is reported as entering homes and readily attacking man, while in others it feeds principally on animals. It is not considered to be of any importance as a malaria carrier in the United States, although in certain regions to the south it is an important vector.

Anopheles franciscanus

In the United States, *A. franciscanus* occurs along the Pacific Coast from southern Oregon to the Mexican border and ranges eastward to western Kansas and Texas. Enormous numbers often are encountered in localities within its range. It does not invade human habitations to any extent and is not believed to be of any importance as a transmitter of malaria. The larvae breed in shallow sunlit pools that are cut off from running water as a stream shrinks and algae develop, and it also has been found in sunlit but cold springs at high elevations.

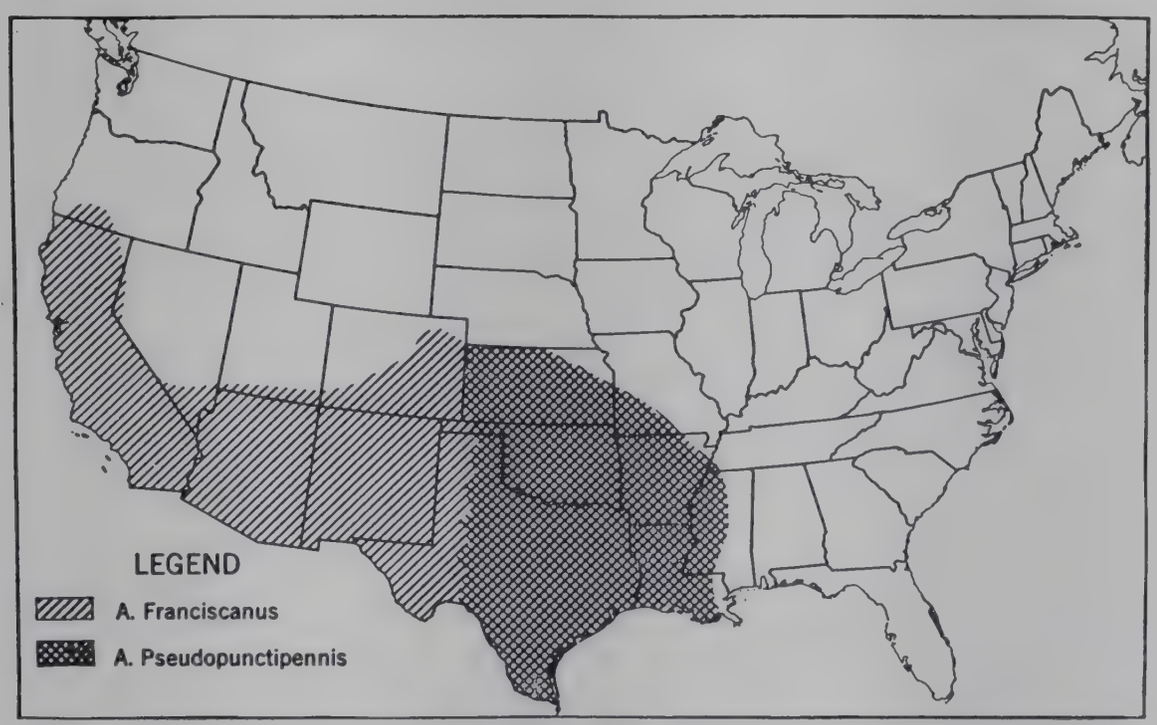

FIGURE 162.—Distribution of *A. franciscanus* and *A. pseudopunctipennis* in the United States.

Anopheles atropos

The typical adult female has almost clear wings and very faintly ringed palps. However, some specimens are occasionally encountered which have rather noticeably marked wings and often there is an almost complete absence of white scales on the palps.

A. atropos (fig. 148) is a salt-water species and breeds in coastal marshes from New Jersey to Texas. Larvae are commonly taken in brackish pools and in very shallow mucky water on salt marshes

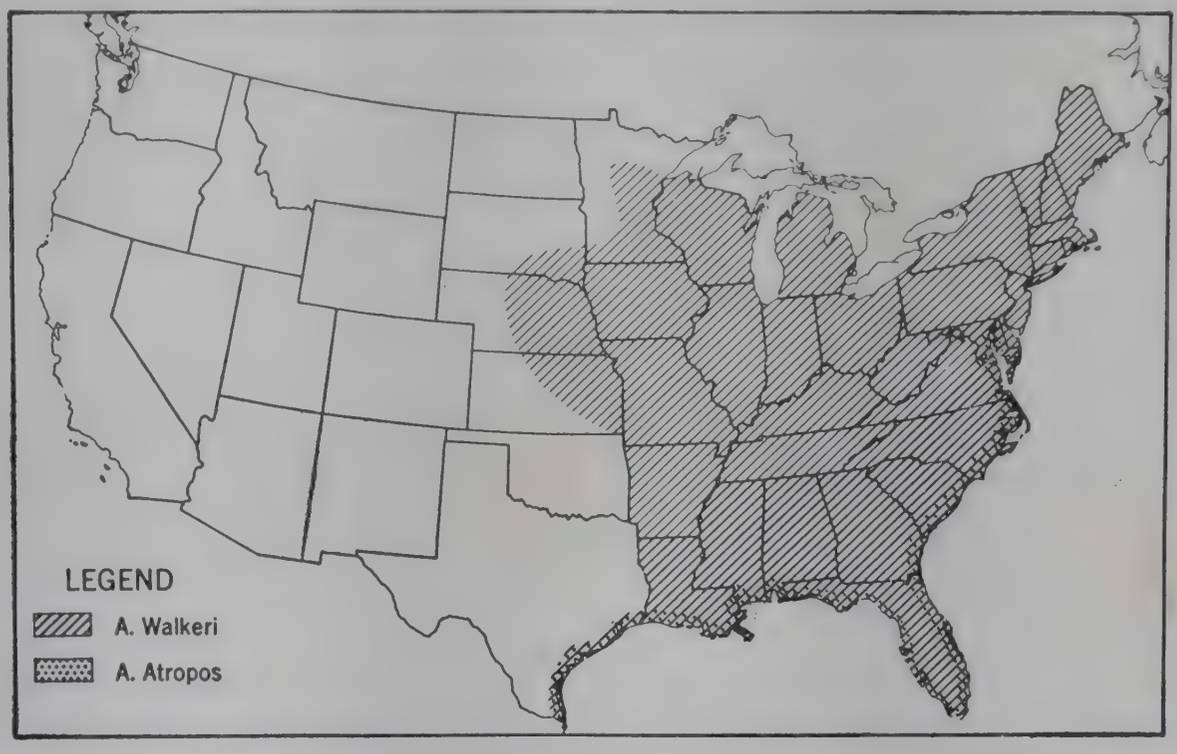

FIGURE 163.—Distribution of *A. walkeri* and *A. atropos* in the United States.

where the water salinity ranges from 3 to 12 percent that of sea water. It is sometimes taken with *A. bradleyi,* but the latter generally is found in water of lower salt content.

A. atropos is a severe biter, both by day and night, and readily enters dwellings. Although it is easily infected with malaria parasites, it apparently is of little or no importance as a vector. *A. atropos* is attracted to lights and may be caught in light traps in considerable numbers. The resting angle assumed is somewhat more acute than that of *A. quadrimaculatus.*

Anopheles walkeri

A. walkeri (fig. 149) is recognized by having four definite spots on the wings, palpi conspicuously banded with white, golden yellow halteres, and whitish knee spots. In coastal regions where *A. atropos* and *A. walkeri* occur together some confusion may occur if *A. atropos* in that locality happens to be of a race showing faint wing markings. However, in such cases the absence of light knee spots in *A. atropos* will separate the two species. The yellow halteres readily distinguish *A. walkeri* from *A. quadrimaculatus.*

In the United States, *A. walkeri* occurs locally in the area extending from the Atlantic Coast to the Great Plains. Formerly it was considered rare, but with the increased attention to anopheline collecting during the past few years it has been found to occur locally in considerable abundance throughout its range. These recent findings probably are largely due to its former confusion with *A. quadrimaculatus* or other anophelines.

A. walkeri is most commonly encountered breeding in sunny marshes or along lake margins among thick growths of aquatic vegetation particularly cattails and sawgrass. It also occurs along the grassy edges of slow-flowing swamp streams and in bordering pools. *A. walkeri* overwinters in the North in the egg stage, a distinct type of "winter egg" being produced in late fall.

It most commonly bites man in the evening and at night, but will also bite occasionally in bright sunlight. The adults prefer to rest on the emergent vegetation of their breeding places, and are seldom found in other resting places. They come readily to lights. The angle assumed while resting is comparable to that of *A. atropos.*

Anopheles barberi

A. barberi (fig. 150) is a very small anopheline which occurs locally over the eastern United States as far west as Missouri and Texas. It is recognized by the unusual length of the bristles on the mesonotum which are about one-third as long as the width of the thorax. The small size of the adults, their unspotted wings, and the fact that their resting stance closely approximates that of culicines frequently cause them to be included in culicine collections. The longer legs in both sexes and the long palpi of the female, however, will distinguish them in cursory examinations. The larvae of this mosquito occur principally in water in tree holes, but sometimes are found in rain barrels and other artificial receptacles.

A. barberi will enter dwellings and will bite humans readily. It has been experimentally infected with malaria parasites but because of its rarity is not considered an important malaria vector, no infected specimens ever having been taken in nature. Occasionally *A. barberi* is taken in light traps but adults are most commonly collected in tree holes where they rest above the water from which they emerged. They sometimes occur in collections taken in sheds, barns, and other natural resting places frequented by *A. quadrimaculatus.*

Anopheles occidentalis

A. occidentalis closely resembles *A. quadrimaculatus* and *A. freeborni* but may be distinguished from these two species by the bright coppery spot on the tip of the wing which includes the wing fringe. This spot is sometimes difficult to see in rubbed specimens. In the United States *A. occidentalis* inhabits a narrow coastal strip along the Pacific coast and ranges from the coast of Oregon and Washington eastward along the Canadian border to the Atlantic. It breeds in fresh water among algae mats and often is found in association with

A. quadrimaculatus and *A. punctipennis* in the northern states. The adults rest during the daytime in barns, cabins, privies, and other usual resting places. During early spring *A. occidentalis* often bites in bright sunlight. It shows little tendency to enter dwellings to bite man and is not believed to be of any importance in transmitting malaria in nature. (See fig. 151.)

MOSQUITO APPRAISAL

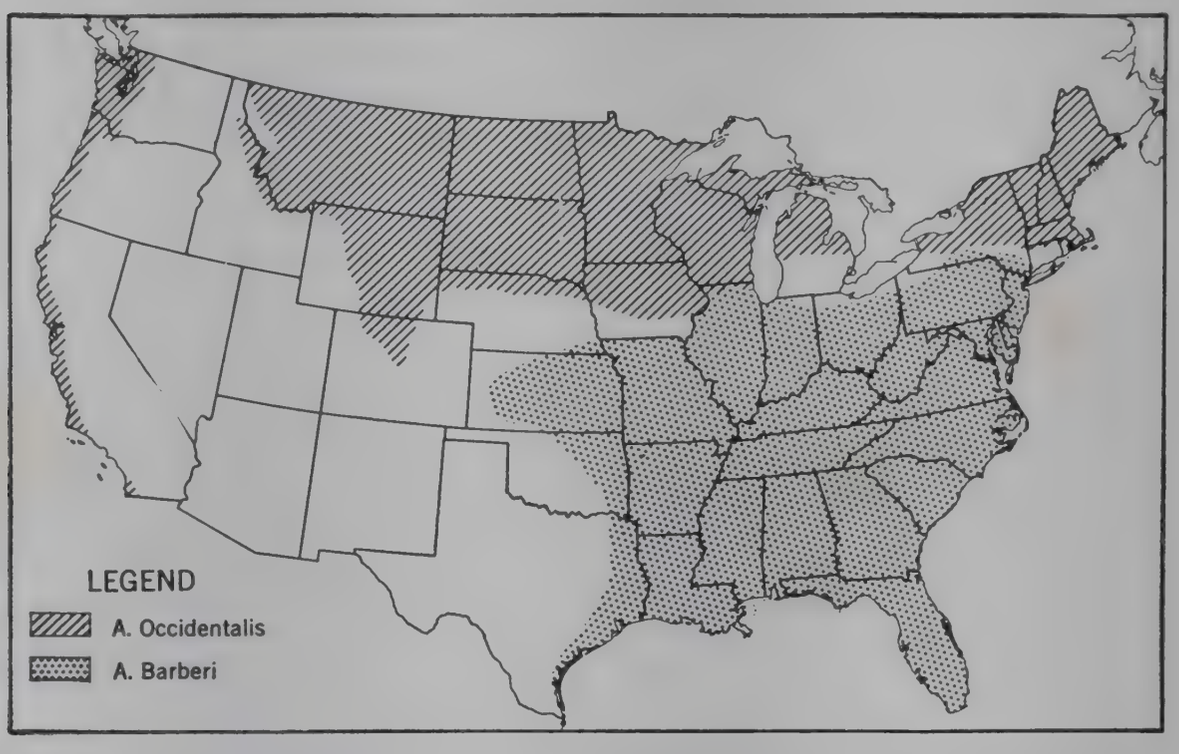

FIGURE 164.—Distribution of *A. occidentalis* and *A. barberi* in the United States.

General

Mosquito appraisal is an essential part of a malaria control program. Determination of the malaria mosquito population is necessary for defining the potentialities of malaria transmission both prior to and following impoundment, and for measuring the effectiveness of mosquito control measures. Inspection for larvae and adult mosquitoes is necessary in planning and appraising antilarval operations (i.e., larviciding, water level management, removal of aquatic plants, etc.); adjusting the program to cope with temporary or emergency situations which may require the use of supplementary measures such as mosquito-proofing or house-spraying; and determining the need for shore line improvements.

One of the first steps in carrying out a mosquito survey is to secure the best large scale map available. This map can be used for orientation, general spacing of inspection stations, and for locating specific places at which inspections are to be made for both larvae and adult mosquitoes. It should also show the maximum pool contour and the upper and lower contours of the "mosquito-control"

fluctuation zone. A map with contours in the fluctuation zone is useful to facilitate the location of flat, shallow areas which will be potential breeding areas for malaria mosquitoes. The effective flight range of the vector (about 1 mile for *A. quadrimaculatus*) should be indicated, paralleling the maximum "mosquito-control" contour. Also, all houses within the flight range zone, existing and proposed roads, and ponds, swamps, sloughs, ditches, and creeks within a 2-mile radius of the maximum "mosquito-control" contour should be indicated on the map. If a suitable map of the reservoir is not available, Geological Survey, State Highway, or Soil Survey maps will prove helpful. In some instances it may be necessary to make original sketches.

Preimpoundage mosquito investigations

The purpose of preimpoundage mosquito inspections is to determine: (1) the species of mosquitoes, particularly anophelines, within the area; (2) the production of malaria mosquitoes under the conditions existing prior to impoundage; and (3) the location of natural breeding situations which may affect mosquito production and adult station counts following impoundment.

The first step in a preimpoundage mosquito survey is to select suitable diurnal resting places for adult mosquitoes and to locate existing and potential breeding areas.

The index stations should be inspected at weekly to monthly intervals over a period of one or more mosquito production seasons prior to the closure of the dam. Data obtained from these inspections will reveal the species present and their relative abundance before impoundment of the reservoir. Later, after impoundage, when antimosquito measures are put into operation, these preimpoundage records may be needed for comparison with the postimpoundage records.

The number and location of preimpoundage stations needed will depend considerably upon the size and type of the proposed reservoir, and the terrain of the adjacent territory within the zone of influence. Most of the adult index stations should be located within the 1-mile zone measured from the contour of the maximum "mosquito-control" elevation or maximum pool elevation depending on the type of reservoir. A few stations should also be located between the 1- and 2-mile limits so as to provide preimpoundage records of the mosquito population in this zone. Dipping for larvae in the vicinity of adult stations will aid in determining the source of the adults collected in the diurnal resting places.

It is well to have one or more adult stations located near each

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sizable human population group expected to be within mosquito flight range of the new lake. Consideration should also be given to the selection of stations which may be utilized for both preimpoundage and postimpoundage inspection so that more direct comparisons can be made.

Postimpoundage mosquito inspection

Postimpoundage mosquito inspections, both larval and adult, are necessary to determine relative rates of anopheline production, to appraise the effectiveness of antilarval measures, and to provide information for planning control measures. For example, before deciding "if," "where," and "when" larvicides should be applied, the malaria control engineer should take into consideration the average number of larvae per dip, the percent of larvae in each stage, the number of adults found in the station for that area, any known or expected changes in the elevation of the pool, and what the mosquito production in that particular or a comparable area has been before under similar conditions.

The number of postimpoundage adult stations will depend primarily on the number of newly created known or potential mosquito production areas within effective flight range of human population centers, and the number of breeding areas outside the impoundment from which mosquitoes may fly into the 1-mile zone around the reservoir.

A suggested procedure for locating inspection stations is: (1) with a detailed map showing potential breeding areas, population densities, etc., begin at the dam and indicate the general location of each proposed station, numbering them consecutively around the reservoir; (2) proceed to the field and select the most suitable diurnal resting places at or near the originally selected locations unless conditions in the field indicate that a station is not needed; and (3) assign each station a number and mark its specific location on the map. Information regarding each station may be recorded on a form similar to that shown in figure 165. For reservoirs with an extensive drawdown, the elevation of the lowest contour in the reservoir that is 1 mile from the station should be recorded on this form. An example of the location, distribution, and number of stations used in connection with a large impounded project is shown in figure 166.

Factors which should be considered in making field selections of adult catching stations are summarized below:

(1) Suitability of structure as a diurnal shelter.
(2) Accessibility.
(3) Proximity to lake margin or mosquito breeding area.

(*A. quadrimaculatus* generally fly only as far as is necessary to find blood and shelter. About 80 percent flying landward from a reservoir remain within one-half mile of the breeding zone—see fig. 157.)

Stations should be selected preferably by a person with adequate field experience regarding resting places of the malaria mosquito. They should be inspected at least once per week during the breeding season unless data over a number of years indicate that less frequent inspections are adequate. Inspections of supplemental stations in the 1- to 2-mile zone will depend largely upon the extent of breeding outside of the reservoir.

To get the best index of actual mosquito production, the stations should be located as close to the reservoir or breeding area as possible. (See fig. 157.) Some stations may be located throughout the 1-mile zone and near population centers in order to obtain some measure of the over-all hazard to the population in the mile zone, and to provide information relating to such control measures as mosquito-proofing, house-spraying, or land-use restriction.

In order to sample adequately mosquito production from reservoirs with wide fluctuation zones, it may be desirable to construct

MOSQUITO INDEX STATION DATA SHEET

Reservoir _____ Index Station _____

Date _____ County _____

Occupant _____ W_____ C_____ No. in House _____

Malaria Survey House No. _____ Owner _____

House Condition (Screening, etc.) _____

Principal Area Control Measure: Larviciding _____ Dewatering _____ Filling _____

Mosquito Proofing _____ Other _____

Station (Barn, Shed, etc.) _____ Roof (Tin, Shingle, etc.) _____

Loft _____ Number and Kind of Livestock _____

_____

Distance to Lake Breeding Area _____ Distance to Outside Breeding Area _____

Describe Outside Breeding Area _____

Remarks _____

_____

_____

_____

Signed

Station Floor Plan Photograph

FIGURE 165.—Form for recording adult mosquito station data.

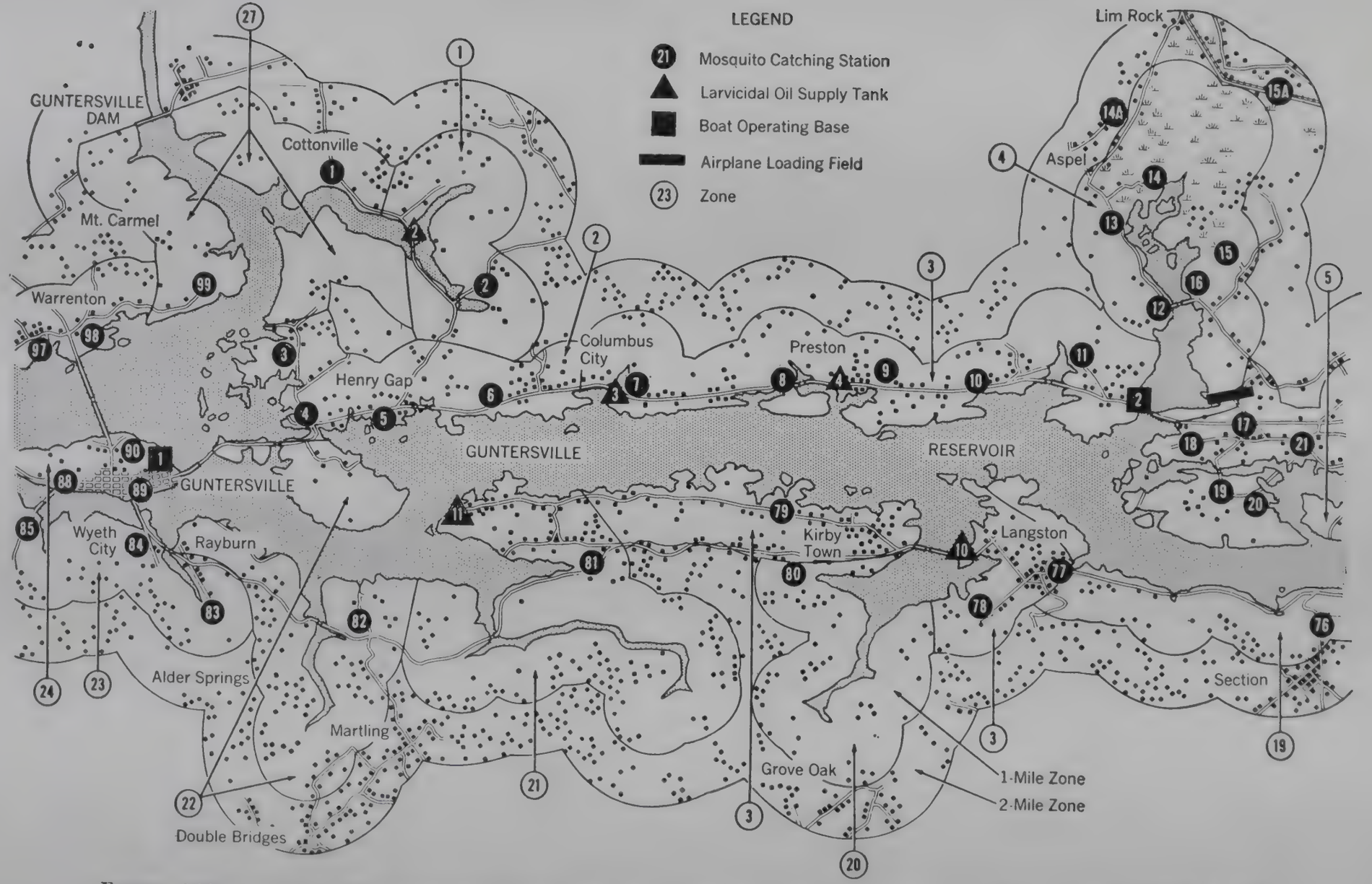

FIGURE 166.—Location of postimpoundage mosquito index stations. Guntersville Reservoir, Tennessee River.

several movable stations and move them about in the zone of fluctuation in order to measure the mosquito production at various lake elevations.

Stations selected to give an index of production outside of the reservoir proper (ponds, swamps, etc.) should be numbered differently from those adjacent to the various production areas around the reservoir. These can be conveniently designated by numbers such as A–1, A–2, A–3, instead of 1, 2, 3, 4 as used for numbering the regular stations for the reservoir. As in the case with preimpoundage inspection, dipping areas for larvae should be located in the vicinity of adult catching stations to facilitate correlation of adult and larvae inspection records. Additional larvae dipping should be carried out to determine specific needs for antilarval measures not adequately defined by adult inspection records.

Two weeks or more prior to the beginning of the mosquito season, an adequate number of larvae and adult mosquito inspectors should be employed to make the inspections necessary to obtain a reliable index of mosquito production. By the beginning of the mosquito season they should have become familiar with the area to which they are to be assigned, and should have received appropriate training and instruction on the collection and identification of mosquitoes.

Generally, a few mosquitoes will be found in the adult stations several days before significant numbers of larvae can be found in typical breeding places. Normally, one might expect to find larvae first; but at the beginning of each season the larval population is very sparse, and the chance of larvae being picked up in the relatively limited area an inspector can sample in a reasonable time is rather small; however, an adult station draws mosquitoes from a much greater area.

The adults of most malaria vectors in the United States have fairly definite macroscopic characters which field workers can soon learn to recognize. On the other hand, the species of larvae cannot be determined reliably without the aid of a microscope.

Adult collecting

Adult *A. quadrimaculatus* are most commonly found resting in cool, dark, damp wind-protected shelters to which they have flown from a breeding area or where they have remained after taking a blood meal. Examples of typical diurnal resting places are barns, animal sheds, houses, privies and other outbuildings, culverts, caves, hollow trees, etc. Under some abnormal microclimatic conditions it may be difficult to find the mosquitoes in these shelters. Sometimes they may be found in buckets, kegs, etc., on the ground, or in a barn loft resting on the undersurface of the roof.

In general, probably the most desirable adult index station is a small barn in which stock are kept at night, located a quarter of a mile or less from the mosquito breeding area. Barns with shaded stalls on the north side are preferable. A barn with a limited number of stalls with low ceilings where the mosquitoes may concentrate is desirable in order to facilitate collection.

It is desirable that the ceiling of the barn be low and within easy reach of the inspector. Barns in sunlight are more attractive to mosquitoes when there is hay in the loft to insulate the ground floor from the heat of the roof. Of course, ideal stations are not always available, but shelters with the above features should be selected wherever they exist. A suitable barn and a typical culvert adult catching station are shown in figures 167 and 168.

Occasionally, suitable structures are not available, and it may be desirable to construct a resting place, or to improve the existing ones by adding boards, stopping cracks with thick building paper, etc. In some instances, it may be necessary to use nail kegs (fig. 169), barrels, boxes, or specially constructed sheds near the breeding areas where no suitable diurnal resting places exist. Extreme care should be exercised in locating these shelters where the microclimate will be favorable for adult mosquitoes. A few feet one direction or the other may make the difference between large numbers in the shelter, or none at all. These shelters should be near the breeding area, close to the ground, in a cool, moist spot which will be shaded throughout the day, and with the opening turned toward the north.

Traps are sometimes used to supplement data obtained from other inspections or to check production in areas where a natural structure is not available. These traps may be of the baited type in which a domestic animal is kept during the night previous to the inspection. The baited trap is especially suitable for determining a satisfactory index for *A. albimanus*. The electric light and fan-type trap (fig. 170) may be used for *A. quadrimaculatus,* but is most frequently used in this country in sampling the general mosquito population. Light traps are especially useful for collecting *A. walkeri* and *A. albimanus*.

Strictly speaking, adult mosquito stations will not yield comparable quantitative data on mosquito densities. However, the mosquito population is usually so small or so large that the counts in individual stations can be interpreted as indicative of no breeding, of sparse breeding, or extensive breeding. Moreover, the exact number of *A. quadrimaculatus* per station which constitutes a malaria hazard is not constant. However, as a working basis, counts ranging from 10 to 20 have been used as indicating the lower limit of signifi-

FIGURE 167.—A common type of mosquito index station.

FIGURE 168.—Culverts may be used as routine or supplemental index station.

FIGURE 169.—Nail keg shelter. (Note surrounding trees and vegetation.)

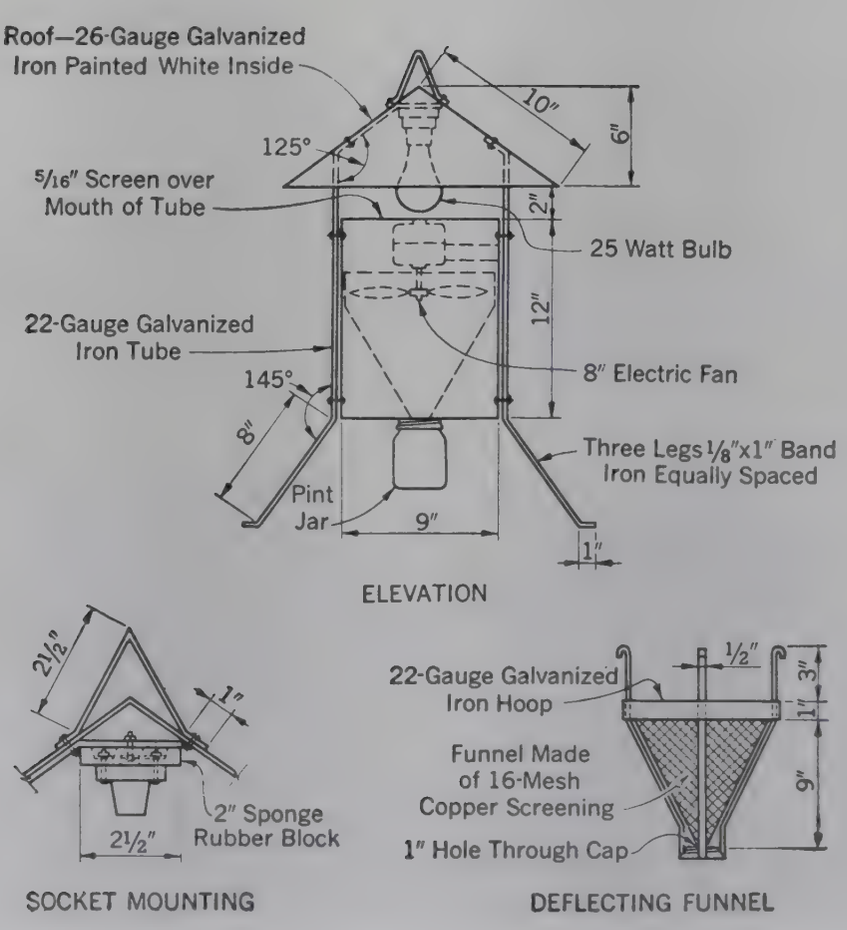

FIGURE 170.—New Jersey-type light trap.

cant production, and the level at which application of antilarval measures should be initiated.

Some precautions can be taken to make station counts more comparable. Ideally, the whole barn or station should be inspected for mosquitoes. In actual practice, this is rarely possible. Instead, inspectors usually count one or more stalls, or estimate the entire number in the barn by counting a representative portion or portions of the barn if the number is too great to count all of them. For comparable data, the same inspector should cover the same stations routinely throughout a season to minimize the personal factor in the results of station counts. Theoretically, more consistent results will be obtained if the station is inspected at the same time of day. In actual practice, it is impossible to carry out inspections routinely with these criteria; however, the closer the inspection procedure approaches this routine, the more valid the results are likely to be.

In figure 171 are shown some adult mosquito collecting apparatus in common use. A three-cell flashlight which can be focused either to concentrate or to diffuse the light at various distances is highly desirable.

A combination catching and killing tube may be made from an

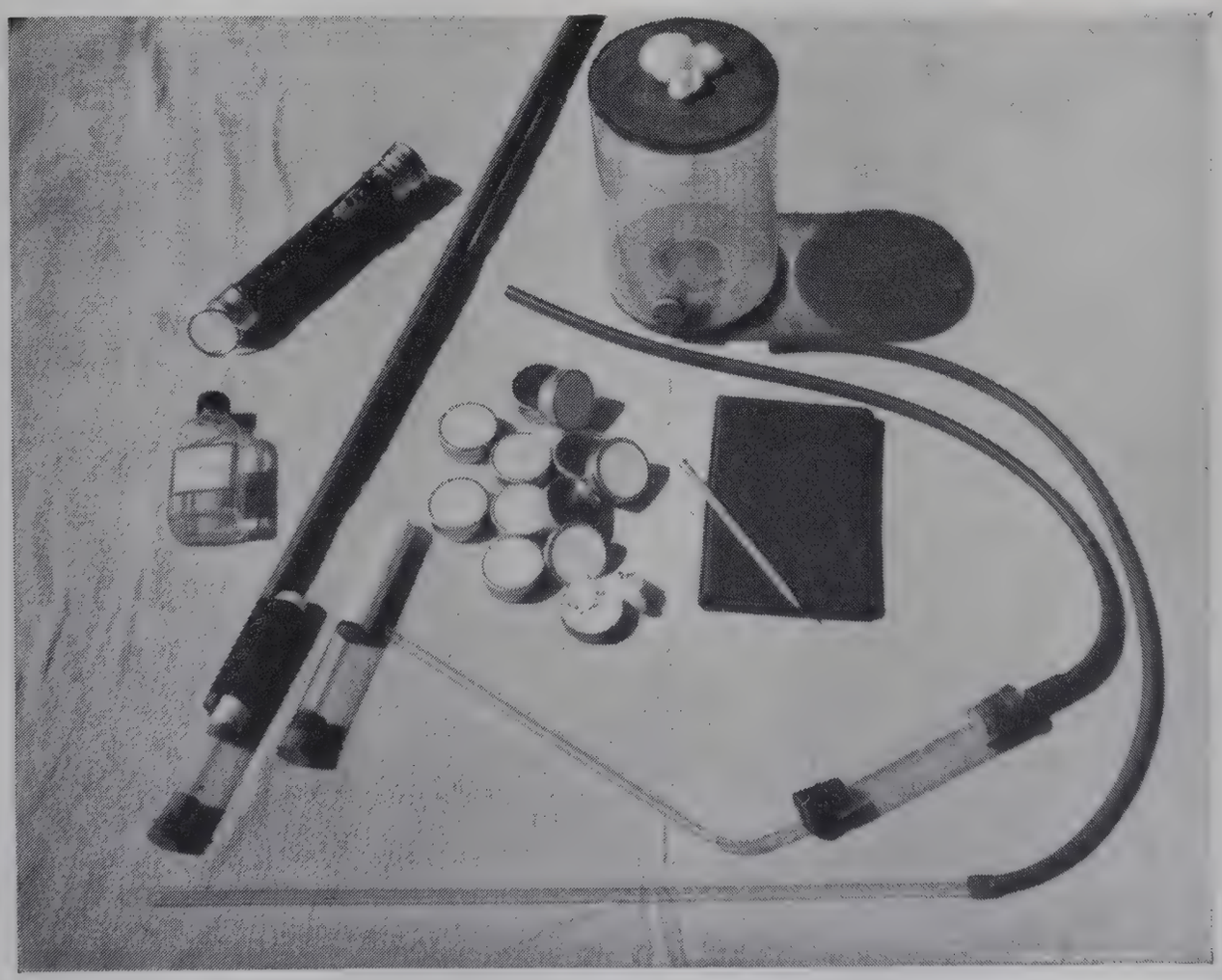

FIGURE 171.—Adult mosquito collecting equipment.

ordinary test tube about 1-inch in diameter and 7 inches long by packing it with cotton or chopped rubber, covering this material with a tightly fitting piece of porous cork, or blotter paper, or very fine mesh brass screen, and saturating with chloroform. A tightly fitting cork stopper should be inserted to prevent evaporation when not in use. It is desirable to have two or more tubes on hand. A stick may be taped to a tube to make it possible to reach mosquitoes resting in high places.

A representative sample of the mosquitoes in a shelter is usually caught in one of the killing tubes. Field identification may be made during capture or as they are transferred to an ointment box in which a thin layer of cotton has been placed. They can then be covered with another thin layer of cotton to prevent shaking around or sticking to the box. Not more than 20 to 30 specimens should be put in each box. Labeling may be more or less complete, depending on the system of records used. The label should have an index number which should also appear on the data sheet which is completed and sent with the boxes of specimens to the laboratory. Here, positive identification may be made of the specimens by a competently trained person. Figure 172 illustrates a typical laboratory set-up for

FIGURE 172.—Identification of mosquito adults and larvae in the laboratory.

mosquito identification. A sample field record form for recording the adult collections is shown in figure 173.

If specimens are to be taken alive, suction tubes as shown in figure 171 may be used. Each is fitted with a strainer to prevent specimens from being drawn into the mouth of the collector. The "reservoir type" permits the catching of several specimens before transferring to a live screen or celluloid cage. Caged specimens should be kept out of direct sunlight or drafts in a covered box containing damp clothes or paper towels.

Larvae collecting

In general, the most likely places to search for larvae in a reservoir are in shallow areas having flotage or emergent vegetation and protected from wave action, with the temperature of the water surface about 70° F. or above. During rainy seasons larvae may sometimes be found in temporary lateral pools and depressions. Many variables affect the location of mosquito breeding, a fact which makes it difficult to predict accurately where larvae will be found. Experience is the best guide.

Frequently, larvae may be found in small depressions or water too shallow for dipping. In these cases the water may be stirred until it is muddy. Larvae soon come to the surface where they may be seen more easily than would have been the case if the water were not disturbed.

Figure 174 shows some of the essential equipment for collecting larvae. An ordinary white enamel dipper with a stick inserted in the handle is most frequently used when qualitative or relative indices of larval populations are desired. If larvae are present in an area, they can usually be picked up by making a sweeping dip with the leading edge of the dipper slightly beneath the water surface. Care should be taken to lift the dipper from the water before it becomes full, otherwise the larvae may be spilled. Figure 175 shows this type dipper being used. The number of dips necessary to sample an area adequately will vary with the size of the production area, the amount of vegetation and debris present, the abundance of larvae, and the desired limits of accuracy of the study. However, dips should be made in multiples of 10 for convenience in averaging records for comparative purposes.

Figure 174, right center, shows a screen-dipper and strainer-pan combination which is recommended for detailed studies when quantitative as well a qualitative findings are desired. The dipper is 4 inches wide and has a screen bottom. By pulling the dipper through the water, with the lip submerged, for a distance of 3 feet, 1 square

INSPECTION FOR ADULT MOSQUITOES

RESERVOIR _____ INSPECTOR _____ DATE _____

STATION	REMARKS	NUMBER OF MOSQUITOES FOUND						
		ANOPHELES						CULICINE
		Quadrimaculatus				Punc	Cruc	
		Counted	Caught	Female	Male			

REMARKS _____

_____

_____

_____

FIGURE 173.—Form for recording adult mosquito inspection data.

foot of surface can be sampled. Then the "catch" can be emptied into the white pan which has previously been partially filled with water strained through the screen lip. The white surface of the strainer pan facilitates counting or collecting any larvae taken in the square-foot sample.

Data may be recorded on a form similar to that shown in figure 176 and kept in an appropriate field book.

Larvae may be transferred directly to small vials from half to two-thirds full of 95-percent ethyl alcohol or 10-percent formalin containing 2½-percent glycerine, by means of a wide-mouthed dropper or an ordinary spoon. As the vial is filled with larvae, the water transferred with them dilutes the preservative to approximately the correct preserving concentration (about 70 percent). Normally, fourth-stage larvae are most practical for identification purposes. Other stages are difficult or impossible to identify and require the use of special keys. If fourth-stage larvae are not present in representative numbers, it may be desirable to bring the immature larvae to the laboratory for further rearing and examination. This being the case, the larvae should be transferred to wide-mouthed bottles about one-third full of water from the area where the larvae are collected. After arrival at the laboratory they may be transferred to

FIGURE 174.—Mosquito larvae collecting equipment.

FIGURE 175.—Use of the white enamel dipper.

rearing pans and fed small amounts of finely ground, dry, dog biscuit or other suitable food.

Each collection should be clearly labeled to show the date collected, area where taken, any special remarks, and the collector's name. Such labels are either glued to the vial or, preferably, written in pencil on white bond paper and placed inside the vial or bottle.

A shoulder bag or satchel similar to the one shown at the left in figure 174 will prove to be very convenient for carrying bottles, a notebook, pencils, etc., and allows both hands to be free.

It is impossible to do good larval inspection without considerable wading, frequently in deep water. Some collectors prefer hip boots for wading and others prefer tennis shoes. Light, well-fitting hip boots should be chosen with care, otherwise a collector's feet may become blistered within a short period of time. In addition to keeping the feet dry, boots offer protection from snakes, "swimmer's itch," brush, and briars. However, they become very uncomfortable if the collector falls or steps in water over the tops and they become filled with water.

INSPECTION FOR MOSQUITO LARVAE

RESERVOIR _____ INSPECTOR _____ DATE _____

LOCATION	CONDITION	NUMBER DIPS		LARVAE FOUND						
				ANOPHELES STAGES						CULICINE
Place Inspected		Total	Positive	Total	1	2	3	4	P	

REMARKS _____

Figure 176.—Form for recording mosquito larvae inspection data.

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XII. MALARIOLOGY

CHARACTERISTICS OF MALARIA

Varieties of clinical malaria

In the introductory chapter it was stated that the term "malaria" refers to at least four different human diseases caused by four species of malaria parasites—*Plasmodium vivax, P. ovale, P. falciparum,* and *P. malariae.* The principal characteristics of the diseases caused by these parasites are discussed briefly in the following paragraphs.

The predominant malaria of the temperate zones is "benign tertian" fever caused by *P. vivax.* Maturation and segmentation of broods of *vivax* parasites requires 48 hours. Thus, when only one brood of parasites exists, fever recurs every other day. However, two broods of parasites are often present in each infection, one of which segments every day, so that fever occurs daily. In spite of treatment, tertian infections tend to relapse for about three years, but infection with this species is rarely fatal. Relapses[5] of *vivax* (and other malaria infections) may be brought on by unusual fatigue, removal to high altitudes, the fracture of a bone, childbirth, or by exposure to sudden changes of climate. The peak of tertian relapses tends to occur in late April or early May in the North Temperate Zone. These spring relapses of *vivax* infections are probably due to a tendency of the first relapse to occur 8 to 10 months after the initial attack, rather than to the influence of the onset of summer temperatures combined with an increase of physical exertion in connection with farm work, as was formerly believed. The clinical expression of relapses is not different from that of the acute initial attack following infection; however, since a certain degree of immunity is conferred by each attack, more parasites are usually found in the blood associated with relapses than with the initial attacks.

Mild tertian fever, caused by *P. ovale,* is found principally in the tropics. It is quite similar to tertian fever, except that the sickness is milder and there seems to be less tendency to relapse.

Malignant tertian fever, tropical malaria, aestivo-autumnal malaria and *falciparum* disease are names commonly used to describe the illness caused by infection with *P. falciparum. Falciparum* malaria is a dangerous disease which often terminates fatally unless it is treated promptly. It does not have a characteristic temperature pattern. As compared to tertian infections, *falciparum* infections are

[5] "Relapse" is used in this manual to refer to clinical expression of malaria parasitemia subsequent to the initial illness.

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short-lived. Most strains survive in man only 8 to 10 months, and as a result this species has a much shorter time in which to escape from man to mosquito to complete its life cycle. This is the malaria infection which is associated with "black water fever." It is characteristically the malaria of the tropics and has a precarious existence in the North Temperate Zone.

Quartan fever is caused by infection with *P. malariae*. Maturation and segmentation of these parasites requires 72 hours; therefore, when only one brood of parasites exists, the fever associated with segmentation occurs at intervals of 3 days. When there is more than one brood of parasites, fever may occur every other day, or may even occur daily. Infection with this parasite is characteristically long-lived in spite of any known form of treatment. There are authentic records of relapses occurring 25 years following the initial attack. This infection seldom occurs in the North Temperate Zone.

Malaria morbidity

In general, it may be said that malaria is pre-eminently a disease which causes prolonged morbidity in rural populations. Aside from the acute episodes of fever which are usually of short duration, the morbidity is caused principally by destruction of red blood cells (anemia). This condition is characterized by weakness and inevitably finds expression in loss of efficiency for work, particularly manual labor.

In the Southeastern States active malaria occurs most frequently in the late spring or early summer and in the early autumn. These periods coincide, respectively, with the time of planting, early cultivation, and harvesting of crops. This fact alone makes malaria a disease of great economic importance.

In the United States, deaths attributable directly to malaria are infrequent, and death rates are low. The debilitating effects of malaria parasitism, however, are contributing causes to morbidity and many deaths attributed to other diseases. Malaria morbidity has been estimated to produce about 3,000 sick days for every death. This ratio is about 475 to 1 for typhoid fever, and 400 to 1 for tuberculosis.

Treatment of malaria

There are three general types of malaria treatment—prophylactic, suppressive, and curative.

Prophylactic treatment refers to the administration of an agent in such a way as to prevent the development of malaria in man. Such an agent would destroy sporozoites or their nonerythrocytic progeny before red cells are infected. There is no known drug which will positively accomplish this although atabrine administered as a sup-

pressive agent apparently acts as a prophylactic against *falciparum* infections.

Suppressive treatment means the use of a drug to prevent the clinical expression of malaria by destroying the parasites soon after they enter the red blood cells. Atabrine administered at the rate of 1 tablet (0.1 gm.) per day will act as a suppressive against all human malaria parasites. Quinine in doses of 0.3 to 0.6 gm. per day will also act as a suppressive.

By curative treatment is usually meant the destruction of sufficient asexual parasites to produce a remission of clinical symptoms. This can be accomplished with either atabrine or quinine. Strictly speaking, curative treatment should be used in the biological sense to refer to destruction of all forms of malaria parasites, thus preventing relapses and the infection of mosquitoes. With the possible exception of atabrine in *falciparum* infections and quinine combined with plasmochin in some *vivax* infections, there is no curative treatment in the biological sense. It seems likely that when a drug is found that is a good prophylactic, it may also act as a curative agent.

Atabrine or quinine in adequate amounts destroys the asexual forms and thus prevents gametocyte production. These drugs will also destroy gametocytes of *P. vivax* and *P. malariae* and tend to diminish the viability of *P. falciparum* gametocytes. Plasmochin, a relatively dangerous drug, will destroy *P. falciparum* gametocytes.

EPIDEMIOLOGY OF MALARIA

Factors concerned in the prevalence of malaria

The transmission of malaria in a community depends upon the existence of four basic variables, namely:

(1) Persons whose blood contains viable malaria parasites (gametocyte carriers).

(2) Persons whose physiology permits the development of malaria parasites (nonimmunes).

(3) Species of anopheline mosquitoes which are efficient vectors of malaria.

(4) Climatic conditions which permit the complete development of the malaria parasite within the mosquito.

When these four basic variables exist to an optimum extent, the stage is set for the transmission of malaria of epidemic proportions. Such situations have occasionally existed in this country in association with the impounding of water. (See ch. I.) As a matter of fact, it may be said that in most situations in the Southeastern States today seasonal increases in prevalence are in effect little epidemics. This does not refer to the occasional sporadic cases occurring in places

where malaria was formerly more or less highly endemic. Rather, it refers to the seasonal occurrence of a considerable number of malaria cases in populations with little or no previous experience with malaria or in which malaria of low endemicity has been present for some years.

The term "endemic" malaria refers to the perpetuation of malaria prevalence in a population group. Today in most sections of the United States where endemic malaria is found, the endemicity (viz, prevalence) is low. There are very few notable exceptions to this generalization. Hyperendemic malaria requires biological conditions which promote the persistence of infections in a population at a high level of intensity. Consequently, malaria of this degree of prevalence occurs most frequently in the tropics. In the past years in the Southeastern States malaria was highly endemic in certain population groups but the general downward trend of malaria prevalence during the past 20 years has largely eliminated such foci.

The decrease and cyclical trends of malaria mortality and morbidity in the United States are shown in figure 177.

Life cycle of malaria parasites in the human host

The reaction of human hosts to malaria parasitism and the life cycle of malaria parasites in the human (endogenous cycle) are essentially the same regardless of the species of malaria parasite. Infection of the human occurs following inoculation of malaria parasites (sporozoites) by infected mosquitoes. Approximately 12 days (for *P. malariae,* 25 to 30 days) after inoculation, parasites first appear in the blood stream (patency), and the first clinical symptoms of malaria infection occur[6]. Fever of 102° F. or higher, due to malaria, is accompanied by demonstrable parasitemia, except sometimes in the instance of *falciparum* infections. Parasites of this species may not appear for several hours after the height of fever, for the reason that segmentation does not often occur throughout the blood stream. In new infections the onset of fever may be associated with very few parasites in the blood. After some tolerance to the infection has been acquired, low fever is often associated with large numbers of parasites; in fact, such high levels of tolerance are achieved (particularly in *vivax* infections) that high levels of parasitemia may be found in the absence of any symptoms.

After the parasites appear in the blood stream, they enter red blood cells where they undergo a stage of development (requiring 48 to 72 hours depending upon the species) which is characterized

[6] The development of the human malaria parasites during the period of prepatency has not been observed. On the basis of animal experimentation, it is believed that the sporozoites enter certain special cells in the spleen and other organs where they undergo a nonerythrocytic stage of development, culminating in the production of parasite forms which are capable of infecting red cells.

by growth and ultimate cell division into 8 to 32 daughter cells depending upon the species involved. After cell division is complete, the daughter cells, called merozoites, are released by rupture of the infected red cells and enter unparasitized red cells. The release of some toxic agent at the time of segmentation apparently is responsible for the production of the chills and fever so characteristic of malaria infections. The destruction of parasitized red cells by special tissue cells, particularly in the spleen, produces an enlarged spleen and anemia. Figure 178 illustrates the various stages of parasite development for the three most common species.

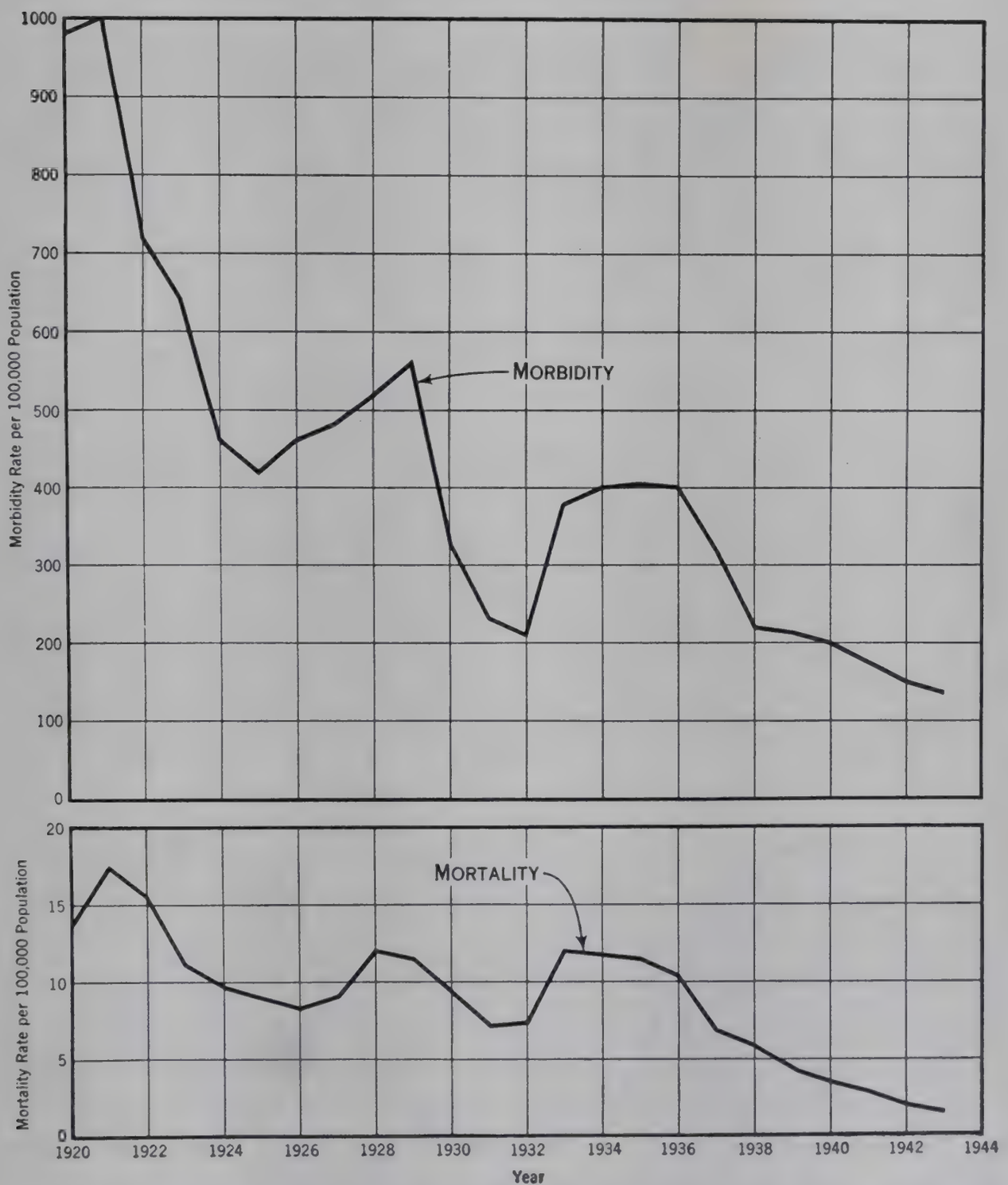
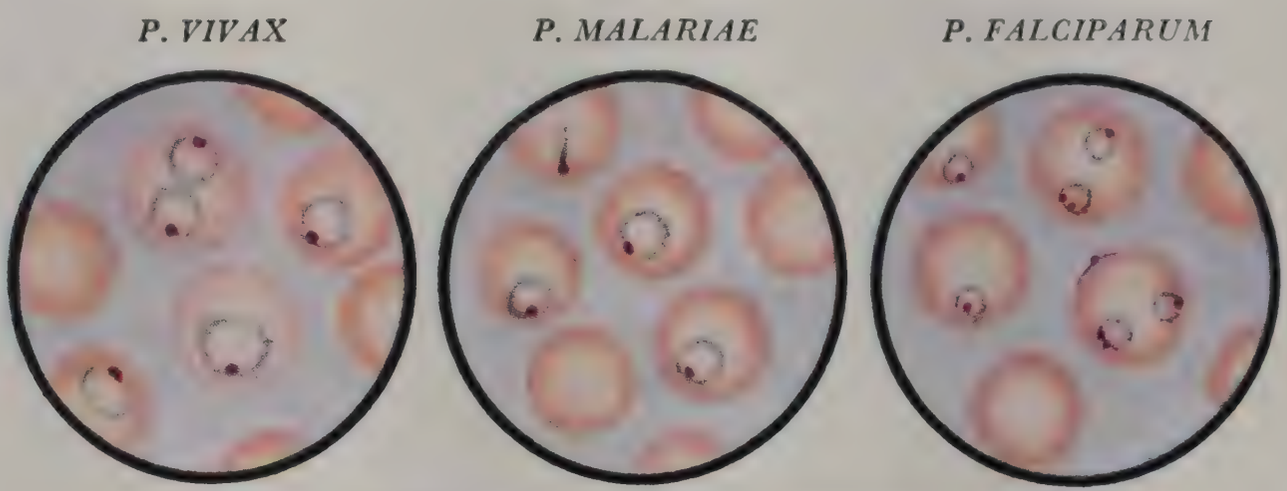
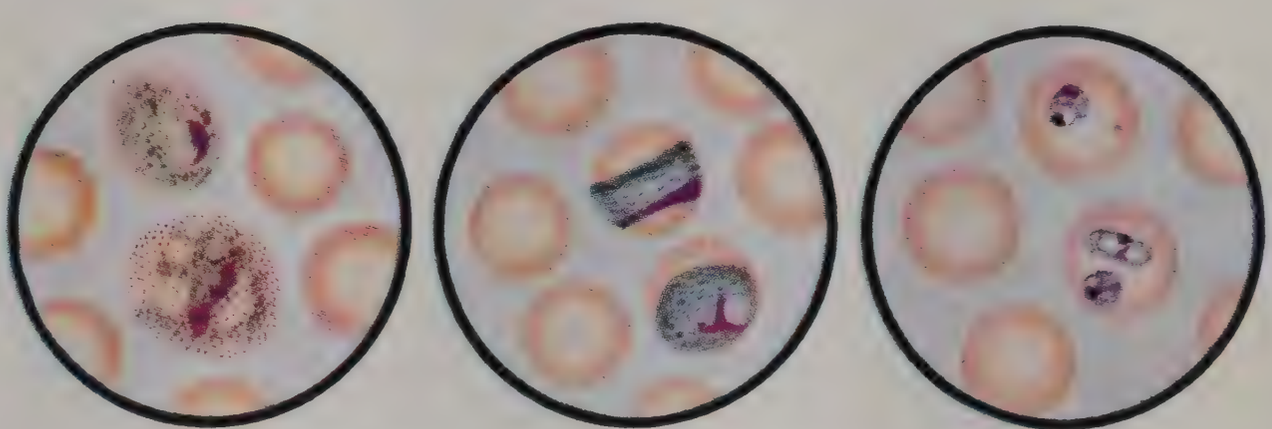


FIGURE 177.—Malaria morbidity and mortality rates in 13 Southeastern States—1920-44. Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, Missouri, North Carolina, Oklahoma, Tennessee, South Carolina, and Texas.

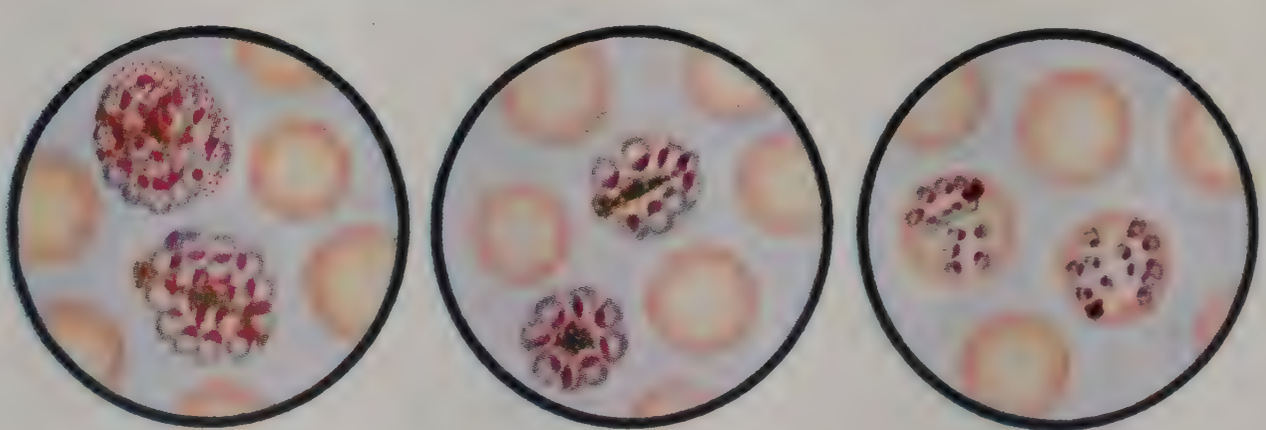


(*a*) Very young trophozoites—ring forms.

(*b*) Amoeboid forms of growing trophozoites.

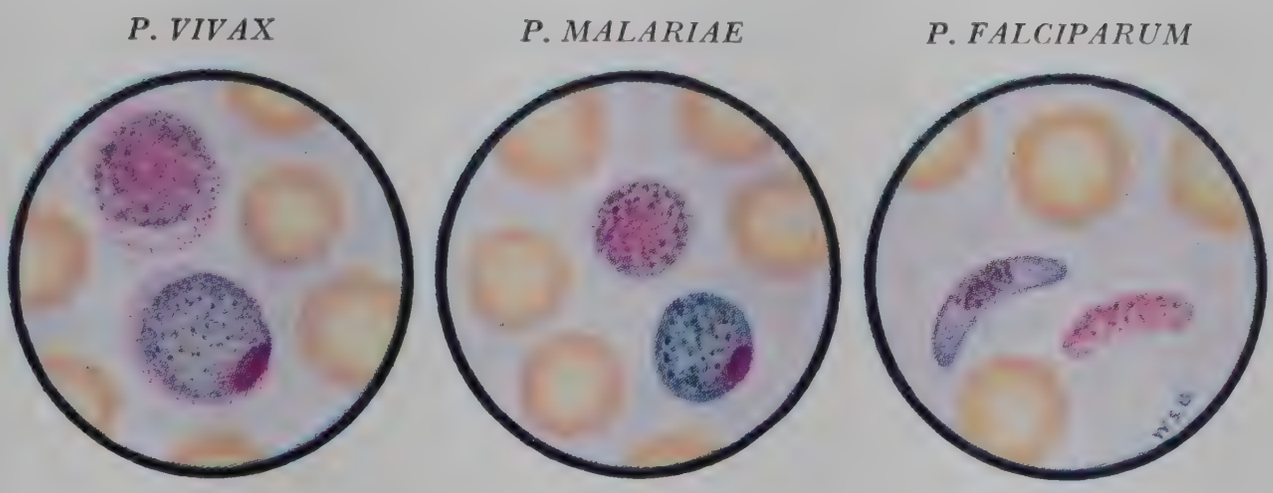


(*c*) Mature trophozoites—"presegmenters."



(*d*) Segmenters.

FIGURE 178.—Various stages of the development of malaria parasites—*P. vivax, P. malariae, and P. falciparum.*



(*e*) Gametocytes.

FIGURE 178.—Various stages of the development of malaria parasites—*P. vivax, P. malariae,* and *P. falciparum*— (continued).

In addition to the propagation of the forms responsible for producing clinical symptoms (asexual forms), certain merozoites develop into special sex cells, called gametocytes, which serve to infect mosquitoes. This alternation of hosts is one of the factors responsible for the complex epidemiology of malaria.

From an epidemiological standpoint there is a very important difference between the production of gametocytes in *vivax* and *falciparum* infections. In *vivax* malaria, gametocytes appear in the blood almost from the onset of fever; but in *falciparum* malaria there is a delay of about 10 days after the first appearance of parasites before gametocytes can be found. *Plasmodium vivax* and *P. malariae* depend for their perpetuation upon the fact that they are capable of going into a sort of hibernation for long periods of time, but relapse at intervals, at which time gametocytes appear in the blood. Continued transmission of the short-lived *falciparum* infections requires the persistence of gametocytes in the blood for long periods of time. Therefore, when conditions are not favorable for the more or less continuous transmission of *P. falciparum* parasites, as is the case in the North Temperate Zone, a period of maximum transmission in the weeks just preceding the end of mosquito breeding is needed if a significant number of *P. falciparum* gametocyte carriers are to be present when *Anopheles* appear the following spring.

Life cycle in the mosquito

The mechanism of the transmission of malaria parasites is essentially the same regardless of the species. When blood containing gametocytes is taken into the mosquito's stomach, the male and female forms of the parasite undergo rapid changes which culminate in the fertilization of the female form. This fertilized cell or zygote

migrates to the wall of the mosquito's stomach and pushes through the lining cells until it comes to rest against the outer membrane of the stomach wall. Here it enlarges by cell division to form an oöcyst. This series of changes extends over a period of about 10 to 13 days (about 20 days in the case of *P. malariae*) resulting in the development within the oöcyst of many oat-shaped structures called sporozoites. The oöcyst then ruptures, liberating the sporozoites which

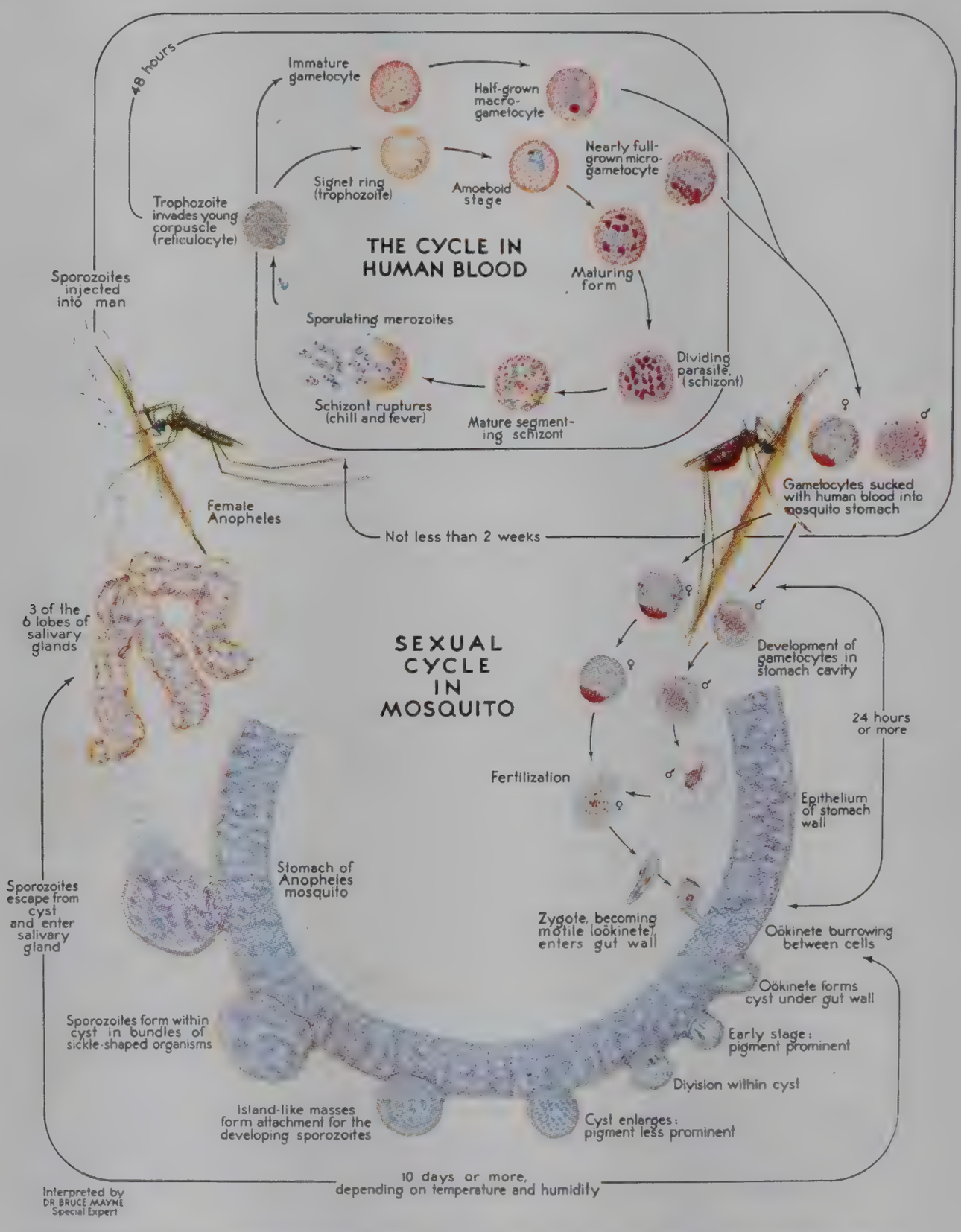

48 hours
Immature gametocyte
Half-grown macro-gametocyte
Nearly full-grown micro-gametocyte
Signet ring (trophozoite)
Amoeboid stage
Trophozoite invades young corpuscle (reticulocyte)
THE CYCLE IN HUMAN BLOOD
Maturing form
Sporozoites injected into man
Sporulating merozoites
Dividing parasite (schizont)
Schizont ruptures (chill and fever)
Mature segmenting schizont
Gametocytes sucked with human blood into mosquito stomach
Female Anopheles
Not less than 2 weeks
3 of the 6 lobes of salivary glands
SEXUAL CYCLE IN MOSQUITO
Development of gametocytes in stomach cavity
24 hours or more
Fertilization
Epithelium of stomach wall
Stomach of Anopheles mosquito
Sporozoites escape from cyst and enter salivary gland
Zygote, becoming motile lookinete, enters gut wall
Oökinete burrowing between cells
Oökinete forms cyst under gut wall
Sporozoites form within cyst in bundles of sickle-shaped organisms
Early stage: pigment prominent
Division within cyst
Island-like masses form attachment for the developing sporozoites
Cyst enlarges: pigment less prominent
10 days or more, depending on temperature and humidity
Interpreted by DR. BRUCE MAYNE Special Expert

FIGURE 179.—Life history of the malaria parasite *P. vivax* in man and the *Anopheles* mosquito.

travel to all parts of the body of the mosquito but concentrate in the salivary glands. When the mosquito bites, some of the sporozoites are injected with saliva into the wound and enter the human circulation, initiating the series of events previously mentioned. This cycle of the malaria parasite in man and the mosquito is shown diagrammatically in figure 179.

Of the many factors which influence the development of malaria parasites in the mosquito (exogenous cycle) that of climate is of major importance. The optimum temperature for the development of malaria parasites in mosquitoes is about 72° F. for *P. malariae,* 77° F. for *P. vivax,* and 86° F. for *P. falciparum.* The malaria zygotes will not develop in the mosquito's stomach at temperatures below about 60° F. although they may continue to survive, at least for short periods, even when the temperature approaches freezing. Malaria parasites can apparently survive for considerable periods in hibernating mosquitoes, and in the southern part of the range of *A. quadrimaculatus* malaria may be carried through the winter in this manner. There is some indication that malaria plasmodia cannot survive in the mosquito at temperatures in excess of about 100° F., but adult anophelines in the United States are probably seldom exposed to such temperatures for any extended periods of time.

The differences in the optimum temperatures for the development of the two species in the mosquito probably explain the relative prevalence of *P. vivax* in temperature climates as compared with *falciparum* infections in tropical climates. Much less is known about the influence of climate on infections with *P. malariae.* It would appear that factors which make for the longevity of mosquitoes and for their more or less continuous propagation would be most influential in determining the prevalence of *P. malariae* infections. Because of the long exogenous and endogenous cycles, about 25 to 30 days each, infections with *P. malariae* do not generally occur to any considerable extent in the North Temperate Zone. However, it sometimes happens that a fairly high prevalence of these infections occurs in this country and elsewhere under conditions which do not differ materially from situations where *P. malariae* infections have never been known to occur.

Other epidemiological variables

From the foregoing discussion it has been seen that a minimum period of 25 to 30 days is required for the events responsible for transmission of malaria parasites from one person to another. Factors which affect the development of parasites in man and in mosquitoes are numerous, but only a few can be evaluated even approximately.

All other factors being equal, the biting rates of anopheline mosquitoes constitute the most important variable in the transmission of malaria. While biting rates are inherently associated with the local density of mosquitoes, they are also influenced by climate and by barriers raised against biting, such as mosquito-proofing. High humidity is not only conducive to anopheline activity, but also to anopheline longevity. Mosquitoes exposed to a constant temperature of 85° F. have a much longer life with a relative humidity of 85 percent than at a humidity 10 percent lower. Low temperatures (65°–70° F.) increase longevity but retard or prevent parasite development.

In general, children are more likely to have clinical manifestation of malaria infection than are adults. In places where malaria transmission proceeds all year and where hyperendemic malaria exists, only children may have clinical expression of infection, although all members of the community may have parasitemia. This is due to the fact that every malaria infection confers some immunity which is strain specific. While there are only four recognized species of human malaria parasites, each species has many strains. Infection with one strain confers little or no immunity to infection with other strains of the same species. In a population that is fixed in the sense that new members are derived principally by birth, a high degree of immunity to local parasite strains may be acquired in childhood. With migratory populations there is also constant migration of parasite strains to new communities and the exposure of persons to parasite strains to which they have had no former exposure.

DIAGNOSTIC METHODS USED IN MALARIA SURVEYS

Blood films

There is only one certain way to diagnose malaria, and that is to find parasites in the blood. Other diagnostic tests may be highly suggestive but they are never fully indicative of malaria parasitism. The tendency for repeated reappearance or persistence of parasitemia, in spite of treatment, has two great fields of usefulness: the clinical diagnosis of malaria and the determination of malaria prevalence.

Either of two procedures can be used in an effort to find parasites in the blood; namely, the preparation and examination of "thick" or "thin" blood films. Each method has its advantages. The thick blood film is particularly useful in survey work for its principle is to concentrate the parasites from several drops of blood in a small area. Therefore, the chances of finding parasites are many times (perhaps 30 times) greater than when the thin film is used. However, on a

thin film the parasites from a single drop of blood are spread over a relatively large area, and species identification is accomplished more easily than in the thick film. While staining techniques are not described in this manual, the steps in making thick and thin blood films are given in appendix H.

If a decision has to be made between the two techniques, the collection of thick films should be chosen since they are most sensitive. From 1934 to 1944, the Tennessee Valley Authority collected both thick and thin films on the same slide. Both films were stained, but the thin film was not examined unless the thick film was positive or was unfit for examination. This method increases survey costs slightly because more time is required to make both films and to stain them. In general, when rates of 5 percent or less can be anticipated and when the diagnostic acumen of technicians is good, only thick films should be made. From a practical standpoint, knowledge of the amount of malaria parasitism is more important than precise definition of species parasitism.

Spleen examination

The fact that malaria produces enlargement of the spleen is utilizable in the determination of malaria prevalence. When malaria is the principal, if not the only, condition which will produce spleen enlargement in an area, the detection of enlarged spleens will give a good idea of malaria prevalence and severity. Another advantage of spleen surveys is that the information obtained is immediately available, whereas it may be weeks or months before data from blood film surveys are available. However, spleen surveys have several disadvantages. The detection of an enlarged spleen, particularly when the enlargement is very slight, requires skill which is not shared uniformly by physicians. Consequently, in order for spleen survey data to be comparable, the surveys should all be done by the same person or at least by a group of persons of known competence. Spleen surveys must be made by physicians or nurses, whereas laboratory technicians may make blood films. The thickness of abdominal walls of adults makes detection of slightly enlarged spleens difficult, and this and other reasons practically limit the use of spleen surveys to individuals 12 years old or less. Spleen surveys give no positive indication of the species of parasites which produced the enlargement. Finally, slightly enlarged spleens may be caused by conditions other than malaria, for instance the contagious diseases of childhood.

Serodiagnosis

Malaria parasitism produces circulating antibodies similar to those produced in bacterial infections. These antibodies apparently

are associated with an increase in a specific protein fraction of the blood plasma. Increases in this specific fraction can be determined biochemically, and the results give a rough indication of the probability of malaria infection. Inasmuch as increases in this protein fraction may be produced by a variety of conditions other than malaria, the method cannot be considered as specific.

Within recent years there has been developed a serodiagnostic test for malaria of fairly high sensitivity and specificity. This is based on the principle of the complement-fixation reaction (Wassermann test) for syphilis. From the standpoint of sensitivity, its positiveness depends upon the presence, or recent presence, of parasites in the circulating blood. Consequently, it is little more sensitive than the thick film demonstration of parasites. From the standpoint of specificity, it has been found that early cases of syphilis will give cross reactions, but otherwise the test is very specific.

The fact that their use depends upon drawing blood from the vein makes serodiagnostic tests for malaria of limited practical usefulness for survey purposes.

MALARIA SURVEYS

Strictly speaking, the term "malaria survey" includes the collection of engineering, biological, and medical information bearing on a malaria problem. However, the term is generally used (and is used in this manual) to refer to the collection of data on malaria prevalence.

The type of malaria survey chosen should be one which will furnish the desired information with the necessary degree of accuracy. A general knowledge of malaria prevalence may be secured from physicians' reports of malaria morbidity and mortality. These reports are notoriously incomplete, but their deficiencies tend to remain constant from year to year, and prevalence trends over a period of years may be determined from their comparison. Morbidity or "history" surveys done rapidly may also be used as screening devices to locate endemic areas. This type of survey is not reliable enough to determine the amount of malaria and, if used, should serve only as a preliminary step in investigations.

Spleen surveys possess disadvantages which have already been discussed. The most accurate measurement of malaria is obtained from blood film and spleen surveys done simultaneously, for the data so secured give a notion of severity, as well as prevalence, of malaria. When a choice has to be made between the two survey methods, blood film surveys probably should be used. Rates based on blood film surveys tend to underestimate the actual prevalence of malaria. However, prevalence rates based on blood film surveys are usually more objective than rates based on spleen surveys, and thus serve

as a better basis of comparison of malaria prevalence between various areas and periods of time.

In places where malaria is highly endemic, spleen surveys can be used to advantage in measuring the effectiveness of control measures over a period of years. This is done by arbitrarily giving an arithmetic "weighting" to spleens of various sizes, computing a mean enlarged spleen size by summating the weights and comparing these means, obtained from repeated surveys, over a period of years.

In planning and executing a survey there are many details which are essential to the successful completion of the job. The principles, in general, are applicable to all types of surveys although they are discussed in relation to blood film surveys in the following pages.

House-to-house versus school surveys

There are two practical ways of applying blood film survey techniques to determine malaria prevalence. These are the collection of blood films and other data from school children ("school surveys") and from entire households ("house-to-house surveys"). Each has its advantages and disadvantages.

School surveys can be done more rapidly and with a minimum of effort and cost because the survey population is concentrated. In the experience of the Tennessee Valley Authority the over-all cost of blood films from school surveys is about half the cost of films from house-to-house surveys. This difference in cost is due largely to mileage and personnel time. A survey party composed of a technician and a clerk can collect about 75 blood films per day in house-to-house surveys, or about 200 blood films per day in school surveys.

From the standpoint of disadvantages in school surveys, perhaps the most important is the difficulty of fixing accurately the location of malaria cases. Ten years ago there was no great difficulty in this regard, for rural schools tended to serve a relatively small geographic area and school populations were consequently small. In those days, even when a child did not know the number of his home, its location could be fixed approximately by determining the direction and distance of the home from the school. Such data were usually obtainable with no difficulty from information supplied by the child and teacher. In more recent years there has been a marked tendency toward the consolidation of rural schools so that a child now may travel more than 20 miles to attend school. While the device of numbering houses should facilitate the location of the homes of children, as a matter of fact, it is surprising how often they do not remember the number. In the event that a request is sent to schools for children to bring in the number of their homes on slips of paper before the school is surveyed, it is often found that many children

forget, make mistakes, or are absent from school on the day of the survey. The consolidation of rural schools has introduced another important factor; namely, the dilution of children from malarious sections with children from nonmalarious sections. With the gradual decline of malaria, the latter component is by far the larger in most consolidated school populations. Separation of the presumably malarious from the presumably nonmalarious children is a task which presents many practical difficulties.

Another serious disadvantage of school surveys is the fact that many rural schools are closed in order to enable the children to help with the crops at the time when a survey is to be done. It often happens also that children with malaria are at home because of illness when a school is surveyed.

Finally, while school surveys, at least in the Tennessee Valley, give a good notion of malaria prevalence in the school population, they fail to give an over-all picture of prevalence in the general population. It is particularly unfortunate that they do not include children of preschool age since examination of infants and very young children is perhaps the best index of recent malaria transmission.

While house-to-house surveys are more tedious and expensive than school surveys, they give information of a preciseness which cannot be duplicated in any other way. The location and age distribution of cases of malaria are accurately determined. When house-to-house surveys are done at a time when schools are in session, the children may not be found at home, but their names can be recorded and the schools can be visited to secure blood films from these children. For these and other reasons, rates from school and house-to-house surveys are not generally comparable.

Date of survey

The date when a malaria survey should be made is determined by the type of information desired. From figure 180 it will be noted that in the Tennessee Valley in North Alabama there are two seasonal peaks of prevalence, one in the late spring and the other in the late summer and early autumn. If the potential for malaria transmission during the oncoming mosquito-breeding season is desired, then the survey should be made in April or early May. If, on the other hand, it is desired to estimate the maximum prevalence of malaria from exposure to anophelism during the season of transmission, the survey should be made in late September and early October. It should be kept in mind, however, that a malaria survey done in the autumn does not give much information on the level of malaria prevalence at any other time of the year, even 30 days before the survey was done.

Administration of surveys

Malaria surveys are normally executed under the direction of local health agencies as a part of their annual program. When field work by several parties is done more or less simultaneously throughout the area, administrative coordination of the survey program becomes necessary. This is ordinarily supplied by the State health department either directly or through a subordinate district organization. It is always advisable to secure as nearly as possible a simultaneous cross section of parasitism. Therefore, the more rapidly a survey is completed, the more nearly this objective is obtained. To this end, supplementation of personnel of local health agencies is nearly always desirable and is often necessary.

The person in charge of an area survey and his immediate subordinates should have their administrative headquarters as near as possible to the geographic center of the area to be surveyed. Adequate provision should be made for liaison between this office and the field. As a preliminary to field work, all field workers should meet for a final briefing by the administrator and should be supplied with detailed directions bearing on the functions of each worker. Field parties are usually made up of two persons, one serving as a clerk, the other as a technician. However, when large schools are to be surveyed, the personnel of these parties should be augmented by one or more technicians and clerks.

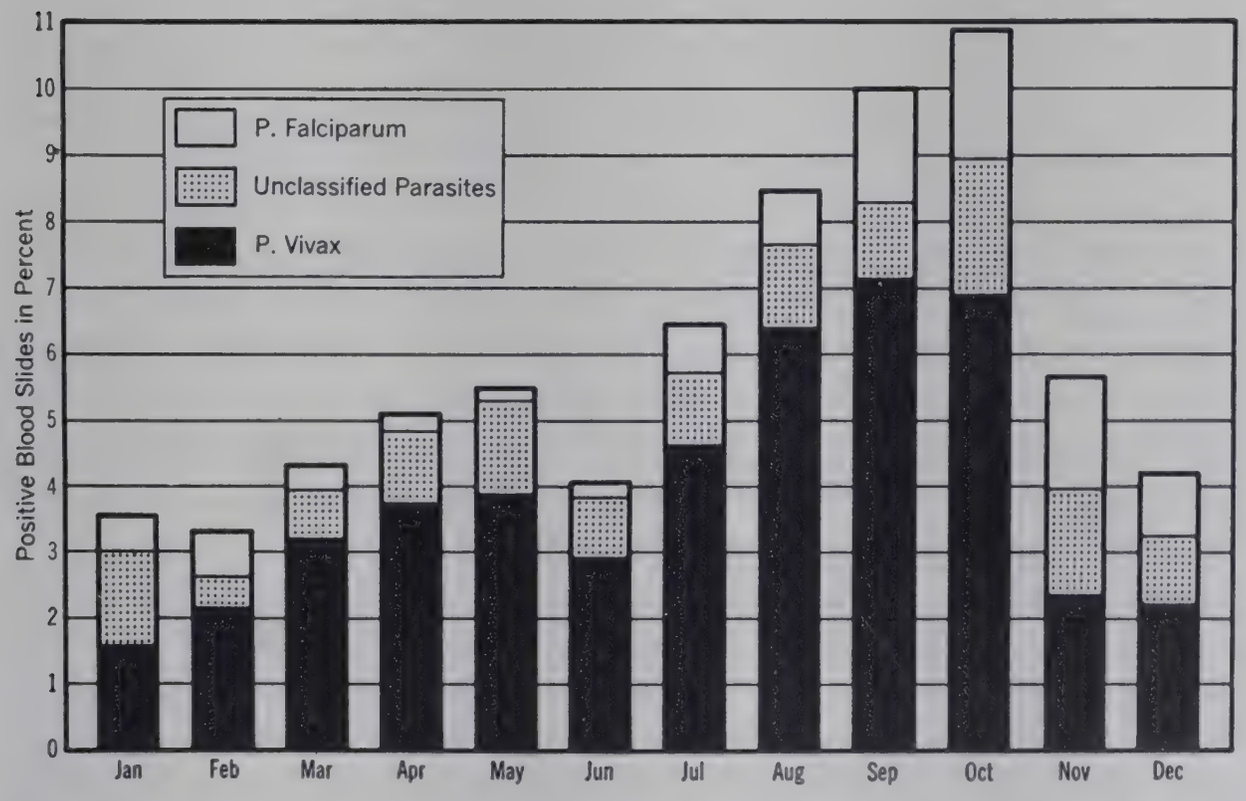


FIGURE 180.—Seasonal variation in malaria prevalence (58,668 routine blood films from North Alabama, 1923-42).

The central administrative office should receive all field reports and corresponding slides, preferably at the end of each work day. This permits the immediate examination of the records by the administrator and their correlation with blood films. Errors detected can then be communicated to field parties for correction before the parties leave the area in which mistakes occurred. Blood films should then be sent to the laboratory for examination accompanied with appropriate identifying records. Whenever possible, the blood films should reach the laboratory within 24 hours after their collection. In order to have uniform results, all laboratory work should be done at one place, preferably under the supervision of a person who can give continuing service over a period of years.

In the interest of developing and maintaining good public relations and of raising the level of public understanding and participation in malaria control activities some form of educational program should be undertaken prior to the surveys. This might take the form of community meetings at which motion pictures, simple talks, and demonstrations would be presented. From the public relations standpoint, of equal importance is the prompt reporting to households of the results of the examination of blood films. If at all possible, arrangements should be made to treat adequately each person found to be infected.

Sampling

To survey a selected population group it is neither necessary nor practical to contact every person. Steps should be taken, however, to provide data which will be representative of the total population; or, if representative of only a portion due caution should be exercised in interpreting the survey results.

Frequently, in surveying a reservoir, certain areas are selected for study because they are expected to yield the highest rates. The survey results, therefore, do not provide a prevalence rate for the entire reservoir but actually give the rate for only the section or sections surveyed. When it is understood that these results are only relative, they may be compared year after year if there is little or no change in the geographic areas selected. The safest procedure, however, is always to compare the same areas.

For long-time studies, geographic areas or persons within these areas should be selected according to a standard procedure. Criteria for area selection may be anopheline density, reported cases of malaria, rates for past years, or a combination of these factors. If certain houses are marked for surveying, the same ones should be visited each year or at least every effort should be made to avoid substitution of houses which have different degrees of exposure to

anophelism. For example, bias will be introduced by the substitution of mosquito-proofed houses for nonmosquito-proofed houses or of houses located near breeding places for those a mile from the reservoir.

After the areas for survey have been chosen, several methods for sampling this subpopulation group are available. "Fifth-family" surveys have been used as one method of selection. These families can be chosen in the field or the houses can be marked on the map before the survey. A number of practical difficulties in this method are obvious: vacant houses, persons away from home, refusals, etc. Valuable time may be consumed in revisiting these houses to contact all members.

Another method is to determine the approximate number of slides to be made in an area. To use this method it is necessary to have estimates of total population and expected prevalence rates. The sample size may be calculated for any proposed degree of accuracy. This number is useful in estimating party days when plans for a survey are made.

To determine the sample size, the formula for sampling a "finite universe" can be used.

$$\delta = \sqrt{\frac{pq\ (N-n)}{n\ (N-1)}} \text{ or } n = \frac{N\ p\ q}{\delta^2\ (N-1)+pq}$$

δ = standard deviation proposed

p = expected prevalence or percent of persons infected

$q = (1-p)$ or percent of persons not infected

N = total population

n = sample required

An example of the use of this formula is given below:

If, in a population of 300 persons, a prevalence rate of 5 percent is expected, how many slides (n) are needed to determine (p) with the required degree of accuracy?

This degree of accuracy is an arbitrary choice, and may be selected as a number representing the amount of variation permissible (e.g., 5 percent $\pm$ 1 percent) or as percent variation of the prevalence (coefficient of variation—e.g. 5 percent $\pm$ 20 percent p). If a variation of the prevalence of 20 percent p is chosen, then δ becomes 0.20 p or $(0.20) \times (0.05) = 0.01$.[7] This amount of variation is usually designated as the standard deviation, δ.

[7] In choosing the coefficient of variation, large percentages should be avoided. In sampling, it must be remembered that the prevalence can be expected to vary by chance as much as $\pm$ 2 δ from the actual prevalence about once in 20 times; or about $\pm$ 2½ δ once in 80 times. In the first example given above, when δ = 0.01 the actual prevalence may be expected to lie between 0.03 and 0.07 about 95 out of 100 times. If large variations are allowed, it is difficult to determine whether the difference in rates for two population groups by this method of sampling is a real or a chance occurrence.

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Substituting in the formula using $p=0.05$, $q=0.95$, $N=300$ and $\delta=0.01$, we have

$$0.01=\sqrt{\frac{0.05\times0.95}{n}\cdot\frac{(300-n)}{(300-1)}}$$

then $n=184$

If the population is 300 and the expected prevalence is 10 percent. δ becomes 0.02 and

$$0.02=\sqrt{\frac{0.10\times0.90}{n}\cdot\frac{(300-n)}{(300-1)}}$$

$n=129$.

Survey procedure

The survey party (composed of a clerk-driver and a technician) should, as previously mentioned, receive a final briefing shortly before the beginning of the survey. At that time the administrator should explain thoroughly the purpose of the survey and the use of data so obtained. Field parties who are "sold" on the survey establish good public relations and have less difficulty obtaining films. Technicians, at this meeting or previously, should receive training and should practice the correct blood-film technique. Field records should be explained carefully and the importance of their complete-

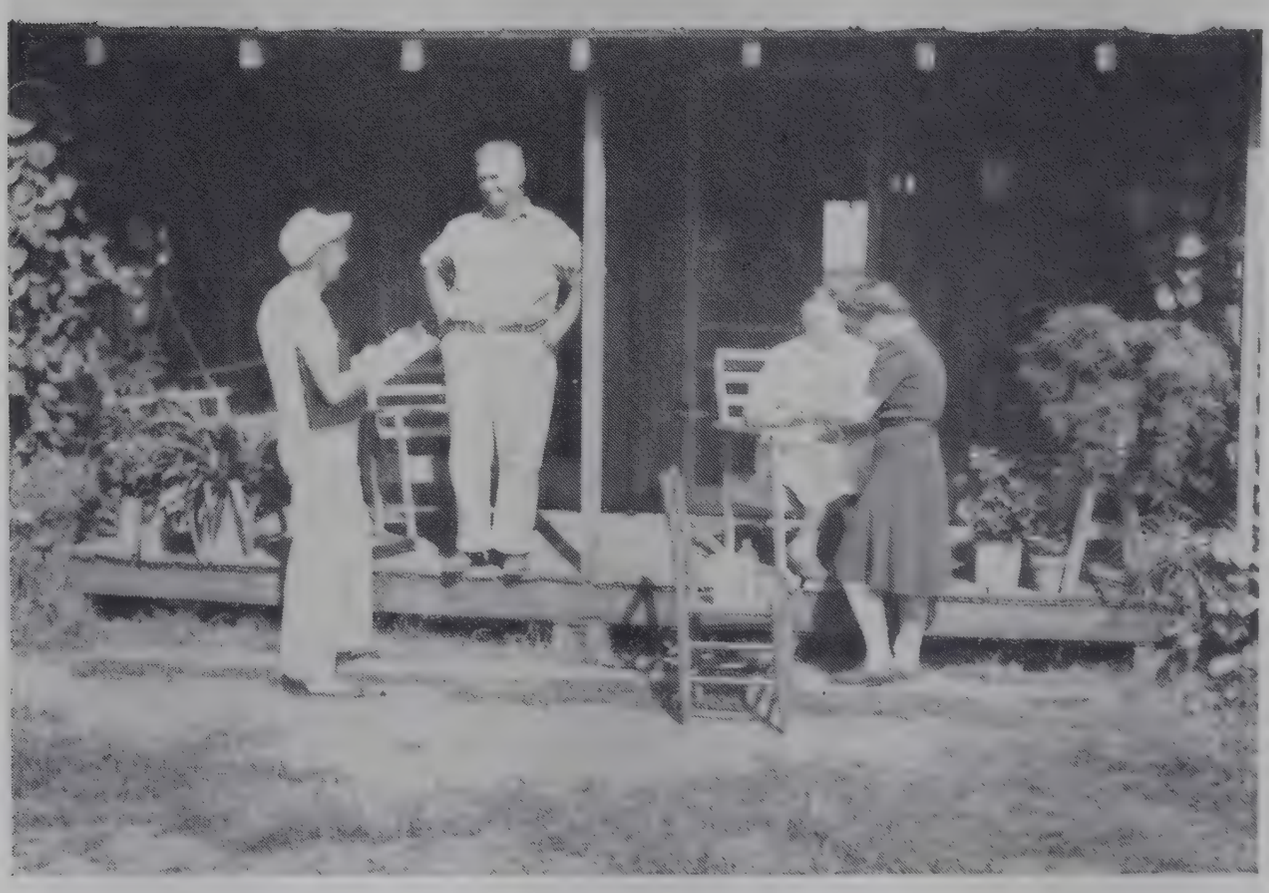

FIGURE 181.—A malaria survey party at work in the field.

ness and accuracy stressed. Field maps (which may be divided into convenient sections and mounted on cardboard) should be studied and instructions should be given for their proper use in the field. Written instructions may be given to each party for study and for future reference.

The party, upon reaching the house (or school) to be surveyed, should introduce themselves as representatives of the appropriate organization (local or State health department, etc.) and explain

MALARIA SURVEY RECORD

Head of Family Day (Last Name) C. M. (First Name) Race W

Location of House:

P. O. Address McKinnon

Reservoir Kentucky County Houston State Tenn.

Area Type II Zone 3

House No. 409 Description of Location*

Distance from Breeding Place ¼ to ½ mi Mosquito Proofed yes

Names of Family Members	Sex	Age	Film Number	Findings	
				Negative	Positive
1 C. M. Day	M	33	8-3-66	X	
2 Lola Day	F	28	8-3-67	X	
3 James Day	M	4	8-3-68	X	
4 Ann Day	F	2	8-3-69	X	
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					

Surveyor Holder and Cloyd

Date 9-26-45

*If house does not have number, location should be described in detail.

FIGURE 182.—Field malaria survey record.

the purpose of their visit. If an educational program has preceded the survey, the introduction may be brief, but it is important that each family understand the reason for the survey. The party should explain the need for the cooperation of all family members and endeavor to secure blood films from all persons present. Records should be completed before the party leaves the house. They should include, as a minimum, proper map notations and a field sheet containing epidemiological data, house numbers, and appropriate symbols for identifying the blood films. Frequent checks are advisable to insure agreement between numbers placed on the slides and those recorded on the field sheet. The field record shown in figure 182 has been developed over a period of years in connection with surveys about impoundages of the Tennessee Valley Authority. For reservoirs with an extensive draw-down, the elevation of the lowest contour in the reservoir that is 1 mile from the dwelling should also be recorded on this form.

Records

Provision should be made for recording data secured during the field work of malaria survey and for a detailed examination of the results of the survey.

Accurate and detailed maps should be procured for use on the survey and subsequent recording of the results. Houses should be numbered and accurately located on these maps. Thus cases of malaria found by a survey can be precisely fixed in relation to other houses and mosquito-breeding places. Perhaps to a greater extent than any other disease, malaria is a disease of place. Therefore, a representation of the exact location of persons from whom blood films were obtained, both positive and negative for malaria parasites, should be shown on maps of surveyed areas. Figure 183 is a section of a typical large-scale field map showing house locations, roads, mosquito-collecting stations, the mile zone, and the results of a malaria survey.

Field record forms should be prepared carefully to provide for recording only such data as are usable and which can be obtained with a reasonable degree of accuracy. Questions which may introduce bias should not be put on the form.

Besides field records, file records are desirable if surveys are large or are continued for several years. The card shown in figure 184 may be used for recording individual blood films made on the survey. These cards provide an easy method of tabulating survey results by age, race, or sex distribution, by reservoir location, etc. Tabulated data of necessity result in generalizations, and broad generalizations are rarely justified in malariology. The tabulations,

FIGURE 183.—Typical malaria spot map.

however, provide important information for large surveys or for long-time studies. Shifts in population composition are indicated as well as species parasitism and prevalence rates by age, race, and sex.

Seasonal studies of malaria morbidity

When malaria endemicity is low, autumnal surveys do not give an adequate notion of the total number of malaria cases that may have been experienced during the season. Where it is desired to correlate control work very closely with the occurrence of malaria cases, the conventional survey methods may be supplemented by special field studies. Experience in the Tennessee Valley has shown that morbidity data can be collected quite accurately by weekly visits of public health nurses to homes in an area under observation. This procedure, however, is expensive and unless special studies are in progress can scarcely be justified.

However, when malaria of low endemicity has been the rule for a number of years, the occurrence of a malaria case is more likely to cause more comment, and to be reported, than in situations where malaria is quite prevalent. The informal reporting of illness believed

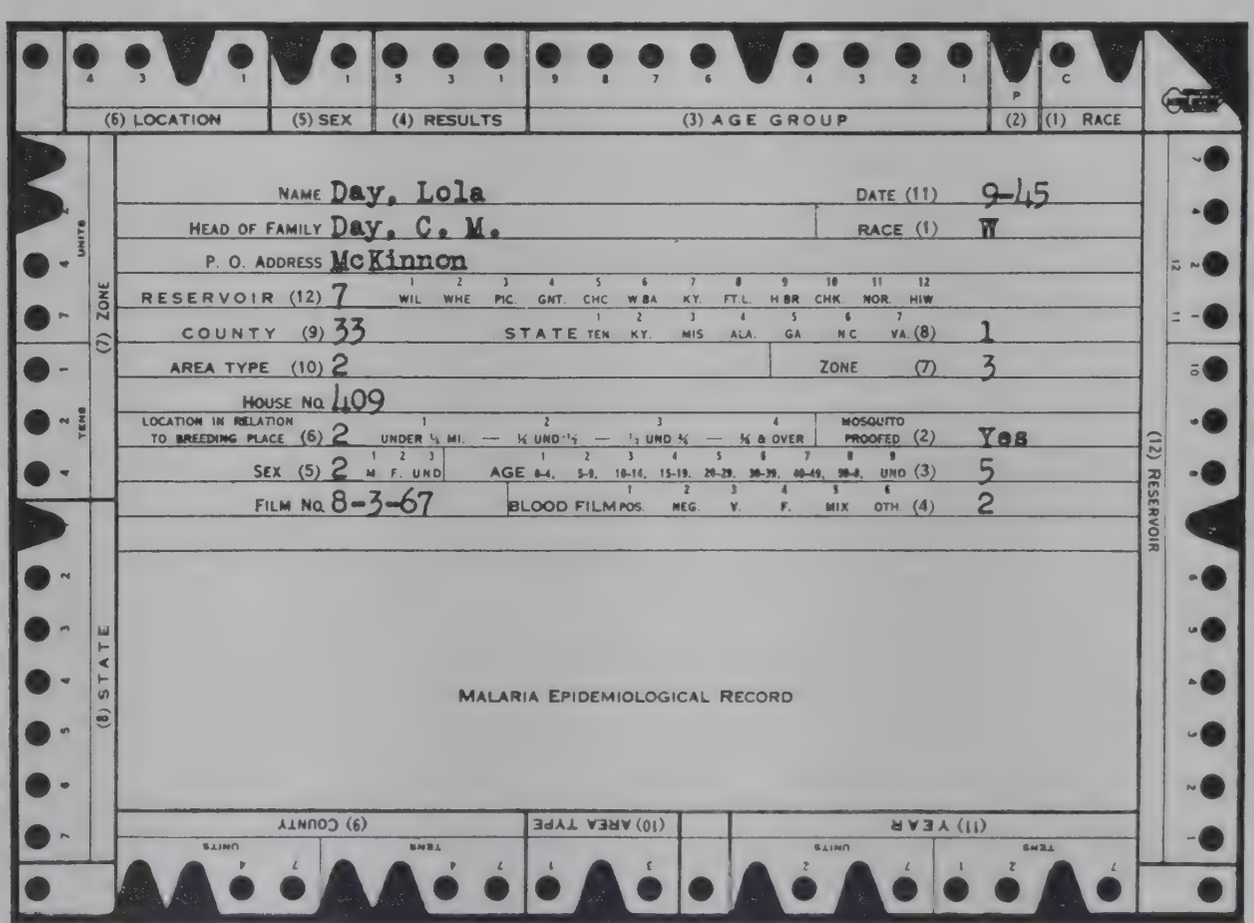

FIGURE 184.—Malaria survey record form.[8]

[8] Information is transferred from the field sheet (fig. 182) to make a file card for each blood film. Items required for tabulation are notched around the margin of the card and the desired groups may be secured by using a steel needle or "tumbler" to collect similar notchings.

to be malaria to field workers on impounded water project, is a usual occurrence, and advantage can be taken of this fact. When such reports are received by the administrative office for a reservoir area, they should be referred immediately to the local health agency. Through a public health nurse from this agency or otherwise made available for the purpose, a field study can be made of the circumstances upon which the report was based. This will permit a reasonably accurate determination of whether the illness was due to malaria and the epidemiological circumstances involved. In most instances, when a field worker has reached the home in which the alleged case of malaria has occurred, treatment will have been instituted with chill tonic or some other medication and blood films will be negative. However, a review of the history of the illness and subsequent observation of the case will usually make it possible to determine within a fair degree of certainty whether the illness was or was not a malaria infection.

Studies of this sort are particularly valuable in areas of low malaria prevalence: they permit the fairly early identification of malaria cases and their prompt and efficient treatment. This is a very important consideration, for without gametocyte carriers there can be no transmission of malaria regardless of the level of anophelism.

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XIII. THE RELATION OF PLANTS TO MOSQUITO CONTROL

GENERAL

One of the oldest and most firmly established principles in the biology of malaria mosquitoes is that a clean water surface is unsuitable for the production of *Anopheles quadrimaculatus*. The production of this mosquito is dependent upon the presence of living plants or plant products (such as seeds, twigs, leaves, or brush) which either float upon or protrude through the water surface. A knowledge of the relation of plants to the production and control of anopheline mosquitoes is therefore of paramount importance in planning and executing a malaria control program on an impounded water project. This knowledge is especially applicable in connection with naturalistic control measures, such as water-level management.

TYPES OF PLANTS

Most malaria control field workers do not have the time or the opportunity to learn the identification of all of the plant species with which the production of anopheline mosquitoes is associated in a given area. A single reservoir may frequently be colonized by several hundred species, many of which even specialists may have difficulty in identifying. It is, therefore, desirable for field men to be able to determine the potential importance of the plants they encounter without reference to their specific taxonomic status. This determination will be facilitated by considering all plants in 10 ecological types which can easily be distinguished in the field on the basis of their growth characteristics, and each of which has well-defined relationships to the production and control of malaria mosquitoes. These types are defined as follows:

Type	*Definition*
1. Woody	Having woody supporting tissue, typically with perennial aerial stems.
2. Erect leafy	Standing erect with relatively firm stems and an abundance of well-defined leaves.
3. Erect naked	Standing erect and usually lacking well-defined leaves, or if leaves are present, they are linear and erect.
4. Flexuous	Having stems which are relatively weak and flexuous, or if firm and erect, possessing lax leaves or flexuous terminal stems.
5. Carpet	With relatively short shoots forming dense attached mats.

6. Pleuston	Minute plants (such as duckweeds) floating freely at the water surface.
7. Floating mat	Composed of relatively large plants forming a mat which floats at the water surface.
8. Floating leaf	Consisting of attached plants bearing floating leaves with relatively long flexuous petioles.
9. Submerged	Typically growing with the vegetative parts largely submerged.
10. Microscopic	Plants which must be identified by the use of the microscope even though some of them, either individually or collectively, may be visible to the naked eye.

Representative species of these 10 types are shown in figure 185. The first 5 types are composed of marginal species which vary widely in the degree of their adaptation to the aquatic environment, and the last 5 types are composed entirely of aquatic species.

Woody species may be classed as intolerant to flooding if they are incapable of surviving in water 1 foot deep for one growing season, as moderately tolerant if they succumb to such flooding during the second growing season, and as tolerant if they survive in water 1 foot deep for two or more growing seasons (table 34). Many of the intolerant species succumb to 1 month or less of flooding.

Type 1—Woody

Type 2—Erect leafy

FIGURE 185.—Representative species of the ten basic plant types.

Type 3—Erect naked

Type 4—Flexuous

FIGURE 185.—Representative species of the ten basic plant types—(continued).

Type 5—Carpet

Type 6—Pleuston

FIGURE 185.—Representative species of the ten basic plant types—(continued).

Type 7—Floating mat

Type 8—Floating leaf

FIGURE 185.—Representative species of the ten basic plant types—(continued).

Type 9—Submerged

Type 10—Microscopic

FIGURE 185.—Representative species of the ten basic plant types—(continued).

TABLE 34.—*Approximate order of tolerance of woody species to inundation in the Tennessee Valley*

INTOLERANT	
Post oak	*Quercus stellata* Wang.
Sugar maple	*Acer saccharum* Marsh.
White oak	*Quercus alba* L.
Yellow buckeye	*Aesculus octandra* Marsh.
Yellow poplar	*Liriodendron tulipifera* L.
Prickly ash	*Aralia spinosa* L.
American beech	*Fagus grandifolia* Ehrh.
Swamp hickory	*Hicoria leiodermis* (Sarg.) Sudw.
Black walnut	*Juglans nigra* L.
Ironwood	*Carpinus caroliniana* Walt.
Redbud	*Cercis canadensis* L.
Red cedar	*Juniperus virginiana* L.
Scrub pine	*Pinus virginiana* Mill.
Shortleaf pine	*Pinus echinata* Mill.
Wild black cherry	*Prunus serotina* Ehrh.
Blackjack oak	*Quercus marilandica* Muench.
Basswood	*Tilia* sp.
Southern red oak	*Quercus falcata* Michx.
Sourwood	*Oxydendrum arboreum* (L.) DC.
Flowering dogwood	*Cornus florida* L.
Sassafras	*Sassafras variifolium* (Sal.) Kuntze
Black locust	*Robinia pseudo-acacia* L.
Shagbark hickory	*Hicoria ovata* (Mill.) Britt.
Mockernut hickory	*Hicoria alba* (L.) Britt.
Chinquapin oak	*Quercus montana* Willd.
White ash	*Fraxinus americana* L.
MODERATELY TOLERANT	
Black alder	*Alnus rugosa* (Ehrh.) Spreng.
River locust	*Amorpha fruticosa* L.
Hispid greenbrier	*Smilax hispida* Muhl.
Red mulberry	*Morus rubra* L.
Wildgrape	*Vitis* sp.
Cow oak	*Quercus prinus* L.
Hackberry	*Celtis mississippiensis* Bosc.
Winged elm	*Ulmus alata* Michx.
Hawthorn	*Crataegus* sp.
Osage orange	*Maclura pomifera* (Raf.) Schneid.
Box elder	*Acer negundo* L.
Loblolly pine	*Pinus taeda* L.
River birch	*Betula nigra* L.
Water oak	*Quercus nigra* L.
American elm	*Ulmus americana* L.
Sycamore	*Platanus occidentalis* L.
Deciduous holly	*Ilex decidua* Walt.

TOLERANT

Silver maple	*Acer saccharinum* L.
Red gum	*Liquidambar styraciflua* L.
Rattan vine	*Berchemia scandens* Koch.
Swamp rose	*Rosa palustris* Marsh.
Florida vine	*Brunnichia cirrhosa* Banks
Dogbane	*Trachelospermum difforme* (Walt.) Gray
Common greenbrier	*Smilax* sp.
Red maple	*Acer rubrum* L.
Persimmon	*Diospyros virginiana* L.
Green ash	*Fraxinus lanceolata* Borkh.
Honey locust	*Gleditsia triacanthos* L.
Overcup oak	*Quercus lyrata* Walt.
Cottonwood	*Populus deltoides* Michx.
Water hickory	*Hicoria aquatica* (Michx. f.) Britton
Swamp privet	*Forestiera acuminata* (Michx. f.) Poir.
Pepper vine	*Ampelopsis arborea* (L.) Rusby.
Trumpet vine	*Campis radicans* (L.) Seem
Sandbar willow	*Salix interior* Rowlee
Black willow	*Salix nigra* Marsh.
Buttonball	*Cephalanthus occidentalis* L.
Tupelo gum	*Nyssa aquatica* Marsh.
Bald cypress	*Taxodium distichum* (L.) L. C. Richard

The herbaceous plants or types 2 to 5, inclusive, may be either terrestrial, wetland, or aquatic species (table 35); these terms (as applied to herbs) are defined as follows:

Terrestrial—Typically growing in relatively dry soil; usually not surviving a month's period of partial inundation during the growing season and frequently killed by a much shorter period.

Wetland—Tyically growing in soils which are saturated with water during a major portion of the growing season; usually not adversely affected by partial inundation during the growing season.

Aquatic—Usually growing in soils covered with water during a major portion of the growing season; development inhibited by extended periods of dewatering during the growing season.

Although it may not be possible to determine whether a species is terrestrial, wetland, or aquatic, merely from its external appearance, it is usually possible to do so by observing the kind of situation in which it naturally occurs (e.g., dry ground, wet seepy areas, or in ponded water). The following table lists typical plants of the various types:

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TABLE 35.—*Representative species of the 10 basic plant types.*

Type	Terrestrial	Wetland	Aquatic
1. Woody	Red cedar	Black willow	—
2. Erect leafy	Cocklebur	Wetland aster	Lizardtail.
3. Erect naked	Blackberry-lily	Spikerush	Bulrush.
4. Flexuous	Crabgrass	Wild millet	Cutgrass.
5. Carpet	Lespedeza	Teal grass	Water purslane.
6. Pleuston	—	—	Duckweed.
7. Floating mat	—	—	Alligatorweed.
8. Floating leaf	—	—	Lotus.
9. Submerged	—	—	Naiad.
10. Microscopic	—	—	Red waterbloom.

TABLE 36.—*Some herbaceous plants completely killed in 30 days or less if continuously flooded by water 1 foot deep during month of June in the Tennessee Valley*[1].

Common Name	*Scientific Name*
Yarrow	*Achillea millefolium* L.
Red top	*Agrostis alba* L.
Lesser ragweed	*Ambrosia elatior* L.
Giant ragweed	*Ambrosia trifida* L.
Broomsedge	*Andropogon virginicus* L.
Dog fennel	*Anthemis cotula* L.
Hairy aster	*Aster pilosus* Willd.
Wild daisy	*Chrysanthemum leucanthemum* L.
Queen Ann's lace	*Daucus carota* L.
Crabgrass	*Digitaria sanguinalis* (L.) Scop.
Wild rye	*Elymus virginicus* L.
White top	*Erigeron annuus* (L.) Pers.
Horseweed	*Erigeron canadensis* L.
White top	*Eupatorium serotinum* Michx.
Bitterweed	*Helenium tenuifolium* Nutt.
Heliotrope	*Heliotropium indicum* L.
Bottlebrush	*Hystrix patula* Muench.
Prickly lettuce	*Lactuca scariola* L.
Pepper grass	*Lepidium virginicum* L.
Lespedeza	*Lespedeza stipulacea* Maxim.
Evening primrose	*Oenothera biennis* L.
Pokeweed	*Phytolacca americana* L.
Bracted plantain	*Plantago aristata* Michx.
Buckhorn	*Plantago lanceolata* L.
Johnson grass	*Sorghum halepense* (L.) Pers.
Goldenrod	*Solidago latifolia* L.
Broadleaf uniola	*Uniola latifolia* Michx.
Mullein	*Verbascum thapsus* L.

In general, terrestrial species occur mainly in the upper portion of the zone of fluctuation; wetland species usually occur down to the lower limit of summer draw-down; and aquatic species often over-

[1] In general, terrestrial herbs succumb to flooding quicker in sandy soils than they do in colloidal clay soils.

lap with wetland species and usually extend out into the reservoir below the lower limit of summer draw-down (fig. 186). This typical contour zonation may not be evident in some situations, such as where there are springs or seepage areas in the zone of fluctuation. In reservoirs having a wide seasonal recession, terrestrial and wetland species offer the principal problem. In such reservoirs, aquatic species may be almost entirely eliminated or may be limited mainly to wet seepage areas.

EFFECT OF PLANTS ON MOSQUITO PRODUCTION

With a few exceptions, any plants which grow in, or are inundated by, water will create a favorable habitat for the production of *A. quadrimaculatus;* however, individual plant species differ greatly in this respect. With the recent development of quantitative methods for sampling larvae (see "Larvae Collecting," ch. XI), it has been possible to investigate the factors which determine the production potentials of plants for *A. quadrimaculatus.* As a result of these investigations, it has been established that the dominant factor in this respect is the "intersection line"—the line of intersection between plants (or flotage) and the water surface. The *A. quadrimaculatus* production potential of a reservoir appears to be directly proportional to the amount of intersection line, other factors being equal. Likewise, the relative anopheline production potentials of different plant types or species are in direct proportion to their relative amount of intersection line per unit area of water surface, other factors remaining equal. Situations with an abundance of intersection line provide *Anopheles* larvae with food and protection from natural enemies and also furnish adult mosquitoes with an ideal environment for oviposition.

Obviously, it is only those portions of a plant which intersect the water surface which are concerned in anopheline production. For example, submerged species are not important except during periods of low water or flowering when they may break the water surface and create high intersection values with a resulting heavy production of *A. quadrimaculatus.* Likewise, leafy erect species may have low production potentials at normal pool levels when the water surface intersects the naked lower portions of the stems, but production of mosquitoes may be greatly increased when the water rises into the upper leafy portions of the plants.

For a given plant species, the intersection value, and therefore the anopheline production potential, will vary according to the percentage of vegetative cover occurring at the water surface. The highest intersection values are usually produced with an interme-

diate cover; low intersection values may be associated with either low or high covers. One of the clearest demonstrations of this relationship is with plants of the floating leaf type such as the American lotus (fig. 187). It is obvious that for either plants or flotage, when the cover at the water surface approaches 100 percent, the intersection line is almost completely eliminated and, therefore, anopheline production potentials are low.

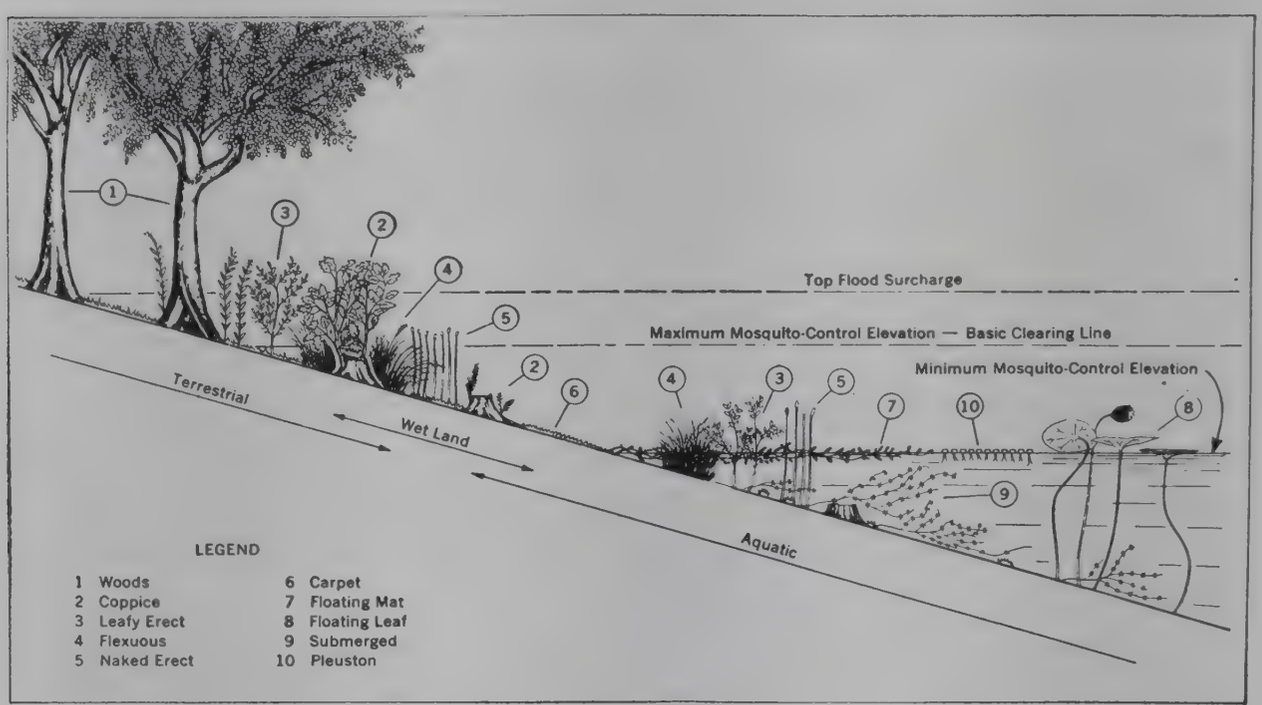

FIGURE 186.—Generalized contour distribution of basic plant types on the shore line of a main-river reservoir with water level schedules as shown in figure 190.

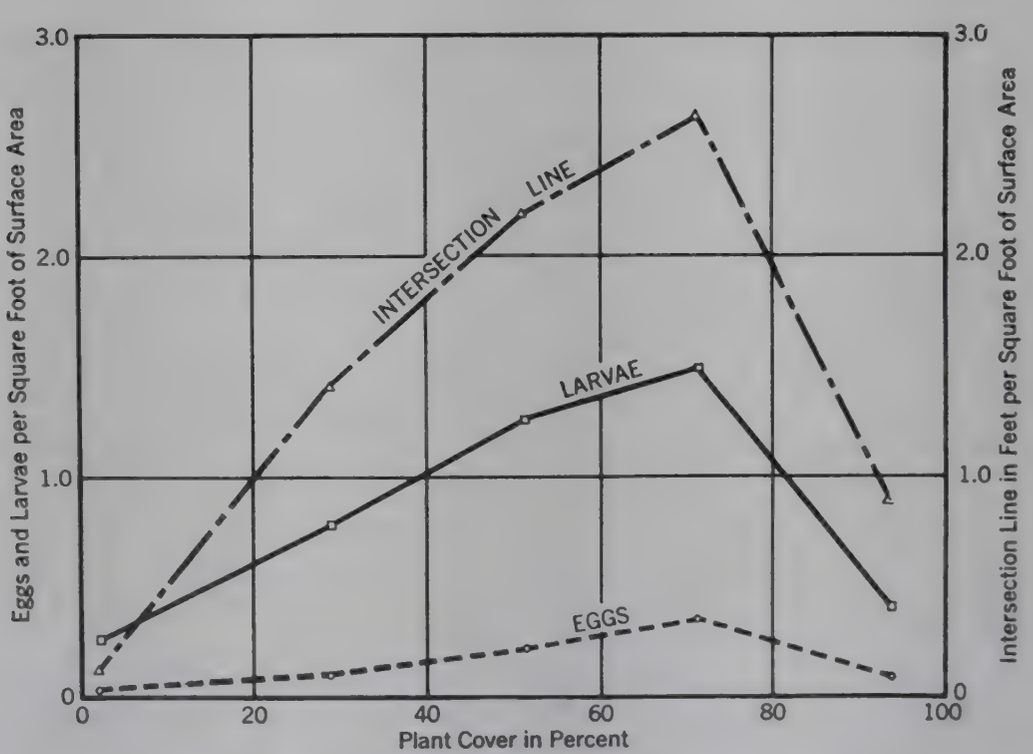

FIGURE 187.—Relation of intersection line to the production of *A. quadrimaculatus* mosquitoes in lotus.

Microscopic plants do not produce intersection line except in some situations such as during the formation of surface mats by certain species of filamentous algae. Such mats have fairly high intersection values and may produce considerable numbers of anopheline mosquitoes. In general, microscopic plants have two important relations to the production of anopheline mosquitoes: (1) they serve as an important source of food for the larvae, and (2) they may frequently serve as biological indicators of unfavorable anopheline breeding conditions. As an example of the latter, water blooms of red or green *Euglena* usually indicate water with high nitrogen and carbon dioxide, and low oxygen content which is an unfavorable habitat for *A. quadrimaculatus*. Figure 188 illustrates some typical quantitative records on the relative *A. quadrimaculatus* production potentials of the different plant types.

As previously stated, almost any plant which intersects the water surface creates a habitat for anopheline larvae and is a potential producer of *A. quadrimaculatus*; however, there are some exceptions. The watershield *(Brasenia schreberi)*, a floating leaf plant which is common in the southeastern United States, is one of these (fig. 189). This plant is characterized by a clear gelatinous coating on the petioles and under sides of the leaf. Larvae of *A. quadrimaculatus* are rarely found in colonies of the watershield. There are probably several reasons for this, such as low intersection values, paucity of food organisms, and acid conditions caused by high concentrations of carbon dioxide. Several other plants have been reported as inhibiting the production of *A. quadrimaculatus*. Among these are the white waterlily *(Nymphaea odorata)* and parrot's feather *(Myrio-*

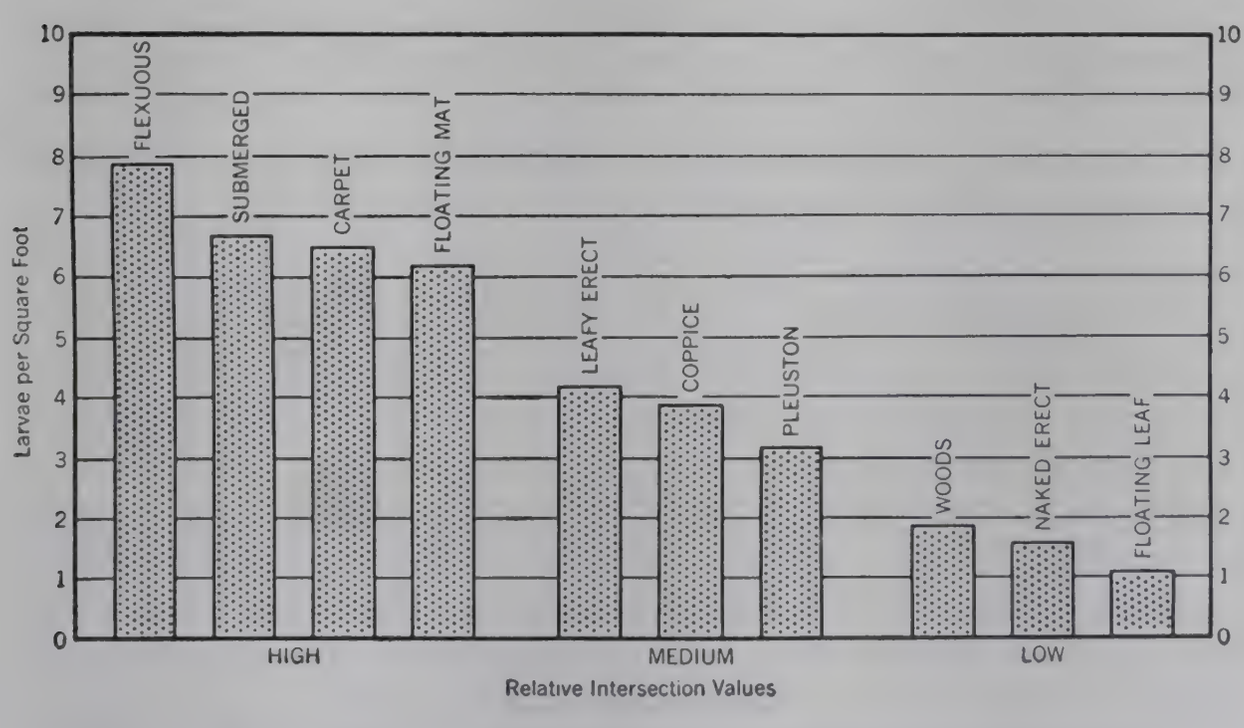

FIGURE 188.—*A. quadrimaculatus* production potentials of basic plant types.

FIGURE 189.—Watershield *(Brasenia schreberi)*—Larvae of *A. quadrimaculatus* are rarely found in colonies of this floating-leaf aquatic plant.

phyllum brasiliense). Some plants which have been reported as inhibiting mosquito production have been shown, at least in some situations, to produce *A. quadrimaculatus* in proportion to the amount of intersection line created. These plants include muskgrasses *(Chara spp.),* bladderworts *(Utricularia spp.)* and duckweeds *(Lemna* sp., *Wolffia* sp., and *Spirodela* sp.). Although duckweeds frequently form dense mats which completely cover the water surface and thus eliminate anopheline production, recent observations show that high production of *A. quadrimaculatus* will occur where these plants only partially cover the water surface.

RELATION OF PLANTS TO RESERVOIR PREPARATION

The relation of plant types to reservoir preparation concerns chiefly the woody species. As pointed out in appendix A, most State health department regulations provide for the clearance of woody species from the reservoir before it is impounded. During recent years, reservoir clearance specifications have included a provision for "low-stumping" in the major problem areas. This low-stumping, in addition to facilitating postimpoundage shore line maintenance, is of marked importance with reference to controlling coppice of water-tolerant woody species such as black willow. Stumps of these

species will not sprout until dewatered but may produce an abundance of coppice if exposed to the air during the full growing season. Low-stumping lengthens the period during which the stumps will be submerged during the growing season and thereby results in decreased production of coppice and quicker killing of the stumps. The treatment of flush-cut stumps of these water-tolerant species with arboricidal oils has also been effective in limiting the production of coppice where the stumps are exposed to the air early in the growing season.

The differentiation between intolerant and tolerant types of woody plants is important in the preparation of the surcharge zone of a reservoir. It is sometimes desirable to remove from the lower part of this zone the most intolerant species in order to prevent their being killed by inundation in reservoirs where the flood surcharge zone is used during the growing season. Such removal prevents the development of drift and flotage and thereby minimizes the malaria control problem. For this reason, provisions for selective clearing in the flood surcharge zone should be included in specifications for reservoir preparation. The tolerance of various woody species to inundation (in the Tennessee Valley) is given in table 34.

Coppice is of particular importance with regard to the final conditioning of the zone of fluctuation of a reservoir just prior to impoundment. Coppice of water-tolerant species will continue to grow in water of considerable depths if portions of the plant protrude above the water surface; however, if this coppice is cut so that it will be continuously flooded during the major portion of the growing season, it will either be killed or its growth greatly retarded. A similar situation prevails with reference to the practice of "topping" tall coppice occurring below the proposed zone of water-level fluctuation. Terrestrial plants of the erect leafy type, such as giant ragweed, are also of importance in relation to the final reconditioning operation. If these plants are not removed, the dead stems persist over winter, collect flotage, and create a mosquito-breeding problem during the initial season of impoundage. (See fig. 52.)

It is frequently desirable during reservoir preparation to eliminate small colonies of undesirable aquatics (such as lotus) which would serve as colonization foci following impoundment.

RELATION OF PLANTS TO WATER-LEVEL MANAGEMENT

During recent years water-level management has assumed an increasingly important role in malaria control programs for impounded waters. The primary objective of water-level management is to provide for the reduction or elimination of intersection line

at the proper time and intervals to insure effective control of anopheline breeding. The type of water-level management schedule which is most applicable on any particular reservoir is a combination of all or a part of the following four phases: Flood surcharge, constant pool, cyclical fluctuation, and seasonal recession. (See "Phases of Water Level Management and Their Application," ch. V.)

A particular phase may function primarily to control larvae, or it may be directed at plants or flotage favorable for the production of larvae. In either case, plant types greatly influence the effectiveness of the operation. The function of the surcharge phase is to strand the winter's accumulation of drift and flotage before the beginning of the mosquito-breeding season. This phase, therefore, is concerned chiefly with flotage produced from woody species and those erect leafy species which have parts which will persist through the winter months. Seeds, particularly of wetland and terrestrial species, are another important source of flotage. Also, those species with stems which remain erect during the winter months collect flotage and prevent it from being stranded during the use of the flood surcharge. (See fig. 52.)

The relatively constant pool phase of water-level management for mosquito control is directed not at the mosquitoes but at the plants which would produce them. In general, all woody species and terrestrial and wetland herbs require dewatering before the seeds will germinate or over-wintering parts will sprout. The constant pool phase is, therefore, intended to delay the initial growth of these species until near the middle of the season and to decrease the extent to which they will invade the zone of water-level fluctuation. The constant pool phase may also serve actually to control woody species and perennial terrestrial and wetland species by keeping the over-wintering parts submerged for a sufficient portion of the growing season either to kill or attenuate them. The use of the constant pool phase during the fruiting period of tolerant woody species, such as black willow, serves to strand the seeds at or above the maximum "mosquito-control" elevation and thus prevents the establishment of seedlings in the "mosquito-control" fluctuation zone. This provides for more effective water-level management and greatly decreases the cost of shore-line conditioning operations.

Plant types are of paramount importance with reference to cyclical fluctuation, which is the third phase of water-level management for mosquito control. This phase has several functions: the drawdown eliminates existing populations of anopheline larvae and inhibits the growth of submerged aquatics, and the return to the original elevation retards the invasion of marginal vegetation. Control

of anopheline larvae by cyclical fluctuation is relatively ineffective in flotage and the floating type plants (floating leaf, floating mat, and pleuston) since these types merely rise and fall with the changing water elevations, thus maintaining their intersection values and the associated populations of mosquito larvae.

Cyclical fluctuation of limited amplitude is also ineffective in flexuous type plants since the flexuous portions of these plants may rise and fall to a limited extent with changing water elevations, thus maintaining a favorable habitat for the mosquito population which they harbor; most effective larval control is, therefore, achieved when this type is completely dewatered at the low point of the cycle.

The coppice and erect leafy types produce leaves only on those portions of the plants which are at or above the water surface. Since intersection values in these types are created principally by leaves, lowering the water elevation down around the naked stems greatly reduces the intersection line and results in effective control of anopheline larvae.

Carpet type plants have high intersection values and, therefore, high production potentials for *A. quadrimaculatus;* however, because of their low height the band of production is very narrow. Under conditions of proper water-level management for mosquito control, plants of the carpet type do not invade the water to any marked extent, and cyclical fluctuation of the usual amplitude of 1 foot is usually effective in controling anopheline breeding in this type of plant.

The naked erect type has relatively low intersection values, and production of mosquitoes in this type is further limited through the creation of a mechanical barrier to the ovipositing adult mosquitoes. Anopheline production in this type is generally not significant and can be controlled by cyclical fluctuation of sufficient amplitude to dewater the plants at the low point of the cycle.

In areas colonized by submerged aquatics, cyclical fluctuation may actually create more favorable conditions for anopheline production if the plants intersect the water surface at the low point of the drawdown; however, the water is usually not held down for a sufficient period of time to result in any significant mosquito production. If submerged aquatics are already intersecting the water surface at or near the top of the water cycle, reduction of the intersection values can be achieved by increasing the water levels and resubmerging the plants; however, experience indicates that situations where this type of upward fluctuation could be effectively used are very limited.

If a reservoir has been properly prepared, there will be no woods (large trees) remaining in the flooded portion of the reservoir dur-

ing the mosquito-breeding season. However, if such a situation does occur, cyclical fluctuation will be effective if the woods are dewatered at the low point of the cycle.

The fourth phase of water-level management (seasonal recession) is used to insure that the water level will be below the main band of vegetation at the low point of cyclical fluctuation. This phase has the same general relationships to the production and control of anopheline mosquitoes in the various plant types as the recession portions of cyclical fluctuation. Seasonal recession is very effective in limiting the development of submerged aquatics in reservoirs since plants of this type are readily attenuated or destroyed by dewatering. Seasonal recession results in the gradual lakeward extension of terrestrial and wetland species which require dewatering in order to germinate, sprout, or maintain significant growth. It is, therefore, desirable to limit seasonal recession to the minimum amount necessary for adequate mosquito control in order to keep the zone of invasion of these plant types as narrow as possible, and thus reduce the cost of the annual shore-line conditioning operation. In this respect a weekly recession rate of 0.1 foot combined with cyclical fluctuation has been found to be ample to insure that the low point of the water is slightly below the lower margin of the main band of invading vegetation. Where seasonal recession is used without cyclical fluctuation the rate of draw-down may need to be increased to 0.2 or 0.3 foot per week, depending upon the rate of the plant invasion.

In addition to the relation of plant types to the normal schedules of water-level management for mosquito control, certain important relationships exist with reference to abnormal schedules of water-level management. For example, summer flooding for even relatively short periods may kill many of the terrestrial herbs (such as cocklebur). Even aquatics (such as lotus) may be killed or greatly inhibited by complete inundation of the leaves for a 2-week period during the growing season. Furthermore, the aquatic types may be either killed or their growth inhibited by extended periods of dewatering during the growing season.

Some of the more important relationships between plants and a typical seasonal schedule of water-level management are shown in figure 190.

RELATION OF PLANTS TO SHORE-LINE MAINTENANCE

Shore-line maintenance is a most important phase of a mosquito control program on impounded waters and is intimately associated with water-level management. The principal operations of shore-line maintenance are rebrushing (removal of coppice), mechanical

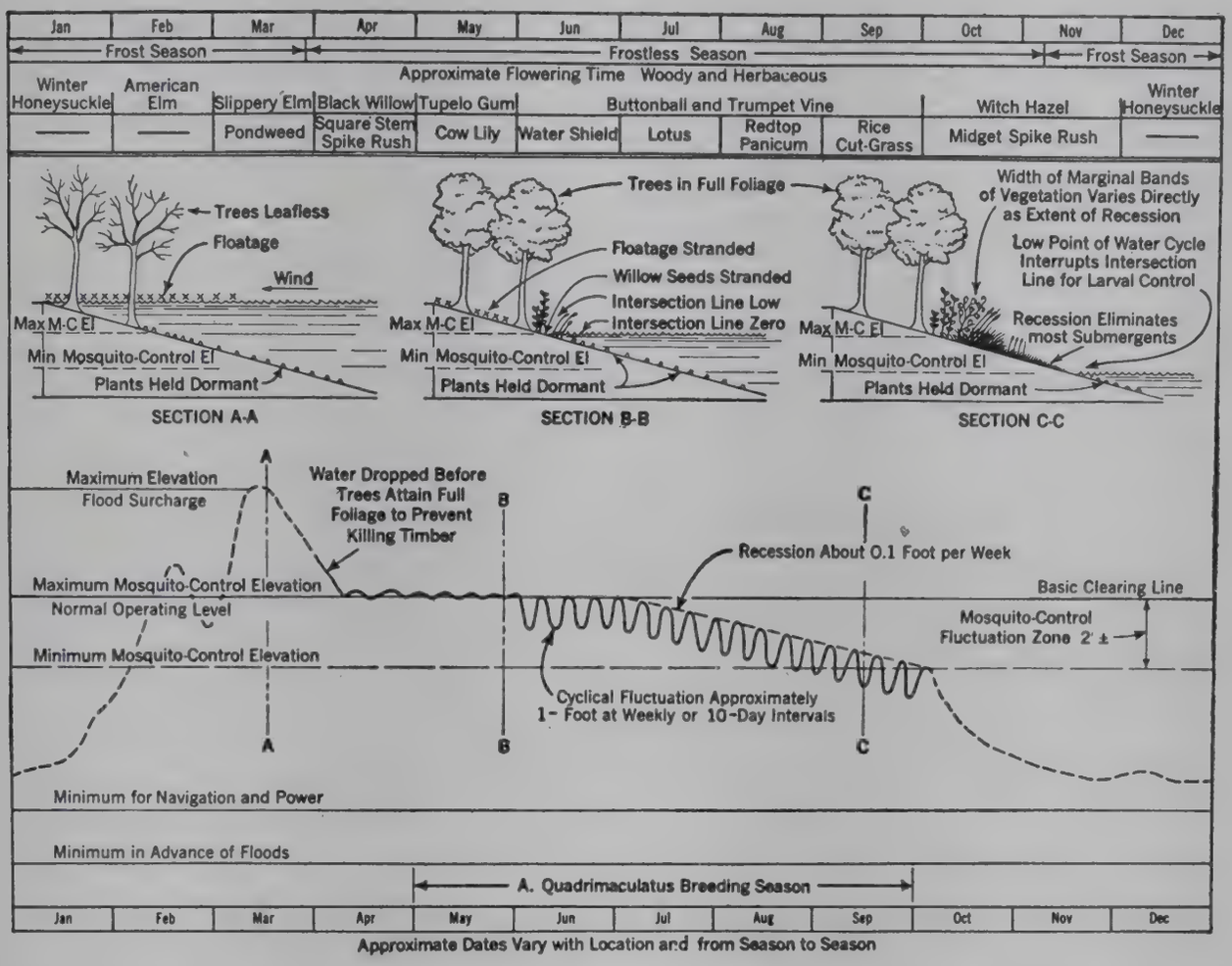

FIGURE 190.—Relation of water-level management to marginal plants (exclusive of deep water aquatics) in main-river reservoirs in the Tennessee Valley.

removal of rough (dead aerial portions of herbs), area burning, and aquatic growth control. (See chapter VI, "Shore-line Maintenance.") Which of these operations will be used in a particular situation is determined primarily by the plant types occurring there. Rebrushing is directed toward the removal of the woody species and, after the first year or two of impoundment, involves almost entirely the water-tolerant type. The above-ground parts of these plants live through the winter in a dormant condition and begin growth in the early spring if exposed to the air; however, if these parts are kept submerged, they will remain dormant. Therefore, the removal of coppice in the zone of water-level fluctuation has a double function: first, to get rid of material which would catch flotage and create intersection line during the following breeding season; and second, to hold water-tolerant species in a dormant condition until later in the growing season, thus greatly decreasing their total amount of growth. Also, many water-tolerant stumps will be killed if the coppice has been removed and they are kept submerged during a major portion of the growing season. With these facts in mind, it is apparent that rebrushing of the water-tolerant woody species is one of the most important operations in shore-line maintenance.

Mechanical removal of rough either by hand or by machine is directed primarily at the leafy erect terrestrials and to a lesser extent to the leafy erect wetland species. All of the leafy erect terrestrials which are of importance to malaria control have stiff erect stems which persist through the winter months and often through the entire following season. If these dead stems are not removed, they will collect flotage and create favorable breeding conditions for *A. quadrimaculatus* during the following breeding season. The same is true of a considerable number of leafy erect wetland species although some of these, like the leafy erect aquatics, have only a small amount of mechanical supporting tissue and, therefore, break down and disappear during the winter months. In general, the leafy erect terrestrials and wetland species will not carry a running fire readily and, therefore, must be either removed by hand or mowed and burned.

The use of area burning is limited almost entirely to areas where terrestrial or wetland flexuous herbs are dominant. The flexuous types include principally the grasses and smartweeds. In general, flexuous species break down during the winter months particularly on sites initially dewatered after May. The small amount of flotage which persists over the winter months will be stranded above the maximum "mosquito-control" elevation in reservoirs with a flood surcharge. Running fires may be used effectively after the first heavy killing frost to eliminate the rough of flexuous species which might contribute to flotage in the reservoir the following season. Running fires are also very effective in controlling seedlings and coppice of water-tolerant woody species where these are associated with dense stands of flexuous herbs. Such use will maintain a marginal band of vegetation dominated by herbaceous species which are more readily managed by water levels.

Erect naked species occur mainly in the wetland group, most of them belonging to the genera *Eleocharis* and *Juncus*. These species usually are of minor importance and usually do not require any shore-line conditioning. However, following very unfavorable water levels, extensive stands of *Juncus* may develop and require mechanical conditioning. Carpet-forming species are also of minor importance and do not involve the use of any shore-line maintenance operations.

The relationships of the aquatic group to shore-line maintenance operations are quite different from those of the terrestrial and wetland groups. As previously indicated, leafy erect aquatics usually contain much less supporting tissue than the terrestrial and wetland species and, as a general rule, the above-ground portions are entirely

dissipated during the winter months. For example, lizardtail is one of the commonest species in reservoirs of the southeastern United States and plays an important role in mosquito production, but it dies down and disappears completely during the winter months. One aquatic of the naked erect type (cattail, *Typha latifolia*) and one of the flexuous type (sawgrass, *Zizaniopsis miliacea*) may require special control measures as their aerial portions persist into the next growing season. Cattail may be effectively controlled either by cutting and flooding or dewatering and cutting. The combination of cutting and flooding has proved to be the most practical means of control for sawgrass. As in the case with terrestrial and wetland species aquatic carpet species are of no importance with reference to shore-line maintenance. The floating aquatics (except pleuston) are of paramount importance and often require the use of special control measures. Two important species of the floating mat type are alligatorweed *(Alternanthera philoxeroides)* and water primrose (*Jussiaea diffusa*) . Experience with alligatorweed in the Tennessee Valley has indicated that this species may be most effectively controlled by drawing the water down during the growing season and applying herbicides to the dewatered plants. Ordinary kerosene has proved to be an effective herbicide for this operation. More recently, hormone-type weed killers, such as 2,4-D (dichlorophenoxyacetic acid) , have shown considerable promise for use in controlling alligatorweed as well as other aquatic and marginal species. Mechanical removal during the growing season of small isolated patches of alligatorweed rooted at lower levels may also be desirable in keeping this species under control. Water primrose has growth characteristics and anopheline production potentials similar to those of alligatorweed. However, this species is much more intolerant to wintertime dewatering than alligatorweed, and this fact is of importance in its control.

The floating leaf aquatics also require special control measures. Two species of major importance are lotus *(Nelumbo pentapetala)* and cowlily *(Nuphar advena)*. Of these, lotus is by far the more important. An effective measure for controlling these species has been found to be recurrent cutting beneath the water surface during the growing season. The use of an aquatic mowing machine, such as the Hockney underwater weed cutter, adds to the facility and economy of carrying out this operation. Recent observations indicate that lotus can be controlled effectively and economically by 2,4-D herbicides applied by ground or airplane equipment at rates of 1 to 3 pounds per acre.

In reservoirs, the occurrence of well-developed colonies of pleuston is limited to a few small spring-fed areas, and this type is of no

importance with reference to shore-line maintenance. Submerged aquatics are, in general, effectively controlled through the use of water-level management and are further limited by wintertime draw-downs for flood control. Therefore, submerged species are not of significance in shore-line maintenance operations.

The use of marginal grazing as a biological means of growth control should be encouraged wherever it fits into the over-all land-use program. Grazing is effective against coppice, most terrestrial and wetland species, and some aquatics; however, there are some species against which grazing is not effective. Notable among these are stinkweed *(Pluchea* sp.), whitetop *(Eupatorium serotinum),* wild cotton *(Hibiscus moscheutos),* purple top *(Vernonia altissima),* lizardtail *(Saururus cernuus),* bitter weed *(Helenium tenuifolium),* daisy *(Chrysanthemum leucanthemum),* and persimmon *(Diospyros virginiana).*

RELATION OF PLANTS TO THE APPLICATION OF LARVICIDES

The most important factor governing the relation of plant types to the application of larvicides is the amount of cover above the water surface. It is, therefore, the coppice, erect leafy, and flexuous types which have the greatest bearing on the effective application of larvicides for the control of *A. quadrimaculatus.*

On large projects the use of airplanes has proved to be the most economical and flexible means of applying mosquito larvicides, and with the advent of DDT the outlook is for even greater emphasis on the use of airplanes rather than boat or hand application. Quantitative studies on the airplane distribution of paris green larvicides indicate that plants decrease the amount of larvicide reaching the water and, therefore, diminish the effectiveness of the operation in direct proportion to the percent cover of their above-water portions. Thus, for equal effectiveness the rate of application must be doubled if the above-water cover is increased by 50 percent (e.g., 10 to 60 percent). In the case of DDT thermal aerosols, it appears that there is less impingement of the larvicidal particles upon the intervening foliage than is the case with paris green. These small aerosol particles appear to "flow around" the vegetation and thus effect much better penetration to the water surface.

In case of flooded woods, the airplane application of larvicides is complicated by the additional factor of the height of the forest canopy above the water surface. Recent experience with the airplane application of DDT thermal aerosols indicates that effective control of *A. quadrimaculatus* breeding in flooded woods can be obtained at

low rates of application. This should not be interpreted as justification for doing away with reservoir clearance, but it does make available a more effective tool for use in emergency situations where heavy production of *A. quadrimaculatus* may result from the flooding of wooded areas.

Plant types, such as submerged, floating leaf, and floating mat, in which the cover is mostly at or beneath the water surface, offer little interference to the effective application of larvicides by airplane. In some instances, the floating mat and floating leaf types may also become leafy erect, and they then have the same relations to the application of larvicides as the normal leafy erect types. Because of the relation of emergent plant cover to the effectiveness of airplane application of larvicides, it is frequently desirable to time the application with the low point of cyclical fluctuation in order that the water may be largely withdrawn from the leafy erect and flexuous types when the larvicide is applied. This will increase the effectiveness of the application and significantly decrease the area of treatment.

Although in many situations airplanes may play the dominant role in the application of larvicides, some application of larvicides by hand and by powered boat units will usually be required. Hand and boat larviciding is generally restricted to relatively abrupt shore lines having a narrow band of vegetation or to small areas inaccessible by airplane. The intersection of the water surface by flotage, mats of algae, or vegetation limits the spread of larvicidal oils and thereby decreases their effectiveness when applied by the usual hand methods. One of the distinct advantages in applying larvicidal oils with power units rather than by hand is that sufficient pressure may be used to drive the oil into vegetation of the floating mat or leafy erect type thereby achieving much more effective control. This is of special importance in controlling breeding in any herbaceous growth with a dense aerial cover.

AN EVALUATION OF THE RELATION OF PLANT TYPES TO MOSQUITO CONTROL

The factors which govern the practical importance of plant types in relation to mosquito control are those which influence the economy and effectiveness of operations directed towards the control of the malaria vector. Thus, the relative importance of a given type is not determined just by its anopheline production potential, but also by the extent of its colonization and the difficulty and expense involved in achieving control of the plant or of the mosquito breeding associated with it. With this in mind, an over-all evaluation may be made of the 10 basic plant types with reference to their potential

TABLE 37.—*Relative potential importance of plant types in relation to the control of* A. quadrimaculatus *on impounded waters (listed in order of importance)*

Type	Anopheline production potential	Reservoir colonization potential	Effectiveness of water-level management		Shore-line maintenance		Application of larvicides	
			For plant control	For mosquito control	Cost	Effectiveness	Cost	Effectiveness
1. Floating leaf	Low	Very high	Low	Low	High	High	Low	Medium
2. Floating mat	High	High	Low	Low	High	High	High	Medium
3. Coppice (tolerant)	Medium	High	Medium	Medium	High	Medium	High to low	High to medium
4. Flexuous	High	Medium	High to low	Medium	Low	High to medium	High	Medium to low
5. Erect leafy	Medium	Medium	High to low	High	Medium	High to medium	High	Medium to low
6. Erect naked	Low	Medium	Low	High	Low	Medium to low	Low	High
7. Submerged	High	Low	High	Medium	None		Low	High
8. Carpet	High	Low	High	High	None		Low	High
9. Pleuston	Medium	Low	High	Low	None		Low	High
10. Microscopic	Low	High	Low	Low	None		Low	High

importance to the control of *A. quadrimaculatus* on impounded waters. This information is summarized in table 37.

The *floating leaf* type is ranked first in importance chiefly because of the fact that plants such as lotus and cowlily have very high colonization potentials and may extend the anopheline-breeding area into deep water. Under normal water-level management schedules, the marginal band of vegetation will usually be restricted to the upper foot or two of contour; however, lotus will commonly grow in water as much as 8 feet deep. It may, therefore, change vast areas of open water into favorable breeding grounds for *A. quadrimaculatus,* thus tremendously increasing the total anopheline production potential of a reservoir. In addition, water-level management is ineffective in controlling anopheline breeding in the floating leaf types, and, therefore, costly plant control or permanent shore-line improvement measures are necessary in order to eliminate the problem.

The *floating mat* type, such as alligatorweed and water primrose, ranks close to the floating leaf in degree of importance. Most species which belong to this type become rooted only in the shallow water near shore, and the amount to which they can extend the anopheline-breeding area out over deep water is limited to one season's growth. Therefore, although this type has a high colonization potential, it is not nearly as high as the floating leaf type. The water hyacinth *(Eichhornia crassipes)* forms unattached floating mats which may develop independently off the shore line. This species, therefore, has a very high colonization potential and might rank of equal or even greater importance than the floating leaf type in some situations; however, there is some evidence that anopheline production is inhibited where water hyacinth forms solid mats of dense emergent stems and leaves. This may be due to a combination of organic decomposition within the mat and the mechanical oviposition barrier to adult anophelines created by the emergent portions of the plants.

Water-tolerant coppice has a high colonization potential, but anopheline production in it may be controlled reasonably well by means of cyclical fluctuation, and the coppice itself can usually be brought under control with proper shore-line maintenance and water-level management.

The *flexuous* type is of much less importance in shore-line conditioning than is coppice. It is ranked above the erect leafy type because it has a higher total anopheline production potential and because its production is more difficult to control by water-level management than it is in the erect leafy type.

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The *erect naked type* is generally of little concern because of its low anopheline production potentials, although some species, such as cattail, have rather high colonization potentials in the zone of fluctuation and may frequently require the application of special growth control measures.

The *submerged aquatic* type has a high anopheline production potential but is of little importance chiefly because of its inability to survive dewatering which greatly limits its colonization potential with proper water-level management. It, also, requires no shore-line maintenance. The submerged type may be of greater importance on reservoirs where the seasonal recession of water level is less than 3 feet and where there is no wintertime draw-down.

The *carpet* type has a high anopheline production potential, but its total production potential is low because it colonizes only limited areas and provides a very narrow band of potential mosquito production because of its low height. This type creates no shore-line maintenance problem.

The *pleuston* type is usually of no concern with reference to malaria control on impounded waters because, with proper water-level management schedules, it is limited to small areas where water is maintained by springs or seepage, and even in these areas it has a very low anopheline production potential.

Microscopic plants are the least important of all the 10 types since anopheline production is rarely directly associated with them in the absence of macroscopic plants. Such breeding as may occasionally occur in floating mats of algae is not difficult to control.

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XIV. INTERRELATIONSHIPS OF MALARIA CONTROL AND WILDLIFE CONSERVATION

GENERAL

During recent years, there has been an increased interest in the development of waterfowl and fisheries resources on impounded waters. Some impoundments are, of course, developed primarily for wildlife purposes, but even those which are not may frequently offer considerable opportunities for wildlife development. It has been demonstrated, for example, that such primary interests as navigation, flood control, and power production are not necessarily incompatible with fisheries and wildlife development. Fish and waterfowl are renewable natural resources, and should be developed and utilized wherever this is not incompatible with other essential functions of an impounded water project.

Some years ago, it was generally believed that malaria control and wildlife conservation interests on impounded waters were completely antagonistic. However, experience in the Tennessee Valley has demonstrated that just the opposite is true; namely, that most of the interests of malaria control and wildlife conservation are mutual. Undoubtedly, similar relationships exist on many other impounded water projects. It is, therefore, of paramount importance in planning and carrying out malaria control in impounded waters that a careful appraisal be made of the interrelationships of malaria control and wildlife conservation. This appraisal should be made by individuals trained in both wildlife conservation and malaria control and should be approached in a spirit of wholehearted cooperation. The wildlife representatives should recognize the necessity for protecting the human population from the transmission of malaria, and likewise, the malaria control representatives should recognize the desirability of developing fish and waterfowl resources. In many instances, the interests of malaria control and wildfowl conservation will be mutual and both programs will benefit by having primary emphasis placed upon these mutual interests.

Where alternative methods of malaria control are available, consideration should be given to wildlife interests in selecting the one to be used. In some instances, the selection of a more expensive method of control may be justified because of the increased advantages to wildlife development.

RESERVOIR PREPARATION

The basic operation of reservoir clearance is desirable for fisheries management as well as for mosquito control since it prevents injurious effects upon the fish population and increases the productivity of the impoundment. The practice of low-stumping problem areas for mosquito control also has advantage in fisheries management. This practice facilitates seining operations following impoundments and may thus be of considerable advantage in connection with commercial fishing and the harvesting of food fish such as carp and buffalo. It also facilitates carrying out fish population studies for use in formulating management practices. It is, therefore, desirable that low-stumped areas be mapped before impoundment in order that they may be fully utilized in carrying out a postimpoundage fisheries management program.

Fisheries management practice frequently calls for submerged brush piles and similar structures to provide shelter for young fish. These are not objectionable to mosquito control if situated below the minimum "mosquito-control" elevation. They may be prepared before impoundment and should be securely anchored in order to prevent their breaking loose, rising to the surface, and adding to the mosquito production potential. Such shelters may even be located in the "mosquito-control" fluctuation zone if they are on abrupt shore lines exposed to wave action. The use of similar brush piles or trees anchored near the maximum "mosquito-control" elevation may also be desirable to create favorable fishing spots for species such as black and white crappie. Here again, if these structures are securely anchored on rather abrupt shore lines exposed to wave action, they will not be objectionable from the mosquito control standpoint. However, the location and construction of fish shelters should be approved by malaria control representatives before they are established.

Marginal drainage for mosquito control is carried out to insure that the water in lateral depressions will fluctuate with the main reservoir and that these depressions will also be accessible by boat. This practice is also beneficial from the standpoint of fisheries management since it prevents the stranding of fish in isolated pools when the water level is lowered.

WATER-LEVEL MANAGEMENT

Water-level management is one of the most important measures for mosquito control on impounded waters and is also highly important in relation to fisheries and waterfowl developments. Although it has often been considered that constant pool levels are

the most desirable from the standpoint of wildlife, it has been demonstrated that properly controlled variations in water level will greatly increase the production of marginal wildlife food plants and may also possibly increase the production of fish through the annual addition of marginally grown organic matter which serves as a natural fertilizer. The relationships of water-level management for mosquito control to wildlife conservation may best be considered on the basis of the individual phases which are used singly or in combination in these schedules.

The flood surcharge phase has little direct relation to wildlife conservation. The use of the surcharge zone for either flood control or mosquito control may, however, provide resting and feeding grounds for waterfowl in the winter or during the migration flights of spring and fall. Such use may also serve to increase the abundance of fish food through the addition of insects and other organisms grown on land. This, however, is probably not important since it has been demonstrated that heavy production of fish may be produced in reservoirs in the complete absence of submerged and marginal vegetation, the food cycle being based upon plankton rather than upon macroscopic organisms.

The constant pool phase is important for mosquito control and is also very desirable from the standpoint of fisheries management. This phase is used during the spring growth period to limit the invasion of marginal vegetation. Many important game fish including the large-mouth bass and other Centrarchidae spawn during this same period. The maintenance of relatively constant pool levels during this period, therefore, provides these fishes with good spawning grounds and insures that the eggs will hatch and the young fish will get a good start before the waters are drawn down. The heavy production of plankton organisms which accompanies the use of the constant pool phase is particularly beneficial to the young fish before they have reached sufficient size to feed upon larger organisms. It is desirable from the standpoint of fisheries management that the water levels should not be drawn down during the peak of this spawning season since this would result in the strandage and destruction of the eggs.

Cyclical fluctuation for mosquito control may possibly decrease the production of macroscopic fish food organisms; however, this may be offset, at least partially, by the fact that it draws such organisms out of the protecting marginal vegetation so that they are available to forage fish such as top minnows which are important in the fish food chain. It is also possible that the productivity of the water will be increased by the alternate flooding and exposure to the

air of marginal organic material. In any event, the use of cyclical fluctuation is frequently an essential element in water-level management for mosquito control and is therefore justifiable even though it may result in some decrease in the production of marginal food organisms.

Seasonal recession of water level for mosquito control may be used either alone or in combination with cyclical fluctuation. Although water-level recession has often been considered as highly objectionable from the wildlife standpoint, it is now known that the intelligent use of this measure may greatly increase the production of marginal wildfowl food plants. The use of the constant pool level in the early spring growth period limits many plants such as ragweeds, asters, goldenrod, and black willow which are of little or no value as wildlife food plants. However, the seed of the most desirable food plants will be held dormant during the constant pool phase but will germinate and grow in profusion on dewatered areas during periods of water-level recession. Valuable wildfowl food plants which commonly flourish in the zone of water-level recession include smartweeds, rice cut-grass, wild millet, teal grass, and chufa and other nutgrasses. Thus, the production of wildfowl food plants around the margins of a reservoir may be greatly increased through the use of a controlled schedule of constant pool level followed by recession which also is effective in controlling malaria mosquitoes. Prevention of excessive water-level recession is desirable both from the standpoint of mosquito control and fisheries management since such excessive recession greatly increases the amount of shore-line conditioning required for mosquito control and decreases the area of fish production.

SHORE-LINE MAINTENANCE

On first thought, it might appear that the annual removal of marginal growth for mosquito control would be objectionable from the standpoint of wildlife conservation. However, it has been demonstrated that just the opposite is usually true. If shore lines are allowed to grow up year after year, a natural succession of plant types will take place leading to the development of dense stands of black willow and other woody species which are of little or no value as wildfowl food plants and prevent the survival or establishment of desirable species. However, when shore lines are conditioned annually, these species are controlled and plant succession is held in the initial stages. This, together with controlled water-level recession, insures the production of the most desirable types of wildfowl food plants mentioned in the section on water-level man-

agement. Annual shore-line conditioning, particularly coppice control, is therefore highly desirable from the standpoint of wildlife conservation and in some instances may be carried out purely for wildlife purposes. Running fires are often used to advantage in removing marginal growth for mosquito control. These fires cannot be used until after killing frosts. At this time, most wildfowl food plants have fruited and shed their seeds so that they are not consumed by the fires. In general, running fires around margins of reservoirs do not significantly reduce the abundance of seeds upon the ground or prevent their germination the following season. In some instances, particularly when burning over relatively dry ground, it is possible that running fires may result in surface burns which will destroy some seeds of food plants. Advantages to wildlife in the use of running fires are that (1) they are usually quite effective in destroying coppice of woody species and insure the continued production of desirable food plants, and (2) they remove rough dead aerial portions of herbs and make the seed crop available for wildfowl.

The removal of marginal growth by mowing may be objectionable to wildfowl interests if it is carried out early in the fall before seeds of food plants have matured. However, this is not the case if the operations are carried on later in the season. In some situations, it will be desirable to coordinate mowing schedules with wildlife interests so that areas which are most valuable from the wildlife standpoint will be mowed later in the season.

The use of disks to condition shore lines or to construct fire lanes has been practiced around some reservoirs. This may prove to be advantageous with reference to wildlife conservation since it conserves organic matter and exposes mineral soils which may readily be colonized the following season by smartweeds, millets, and other valuable wildlife food plants. It is now well established that the production of waterfowl food plants may be increased by measures such as this which set marginal plants back to earlier stages of succession.

In addition to the usual shore-line conditioning operation, a malaria control program may require the control or eradication of certain objectionable aquatic plants. These objectionable plants include alligatorweed, lotus, cattail, giant cutgrass, water chestnut, and water hyacinth. In general, these plants are also objectionable from the standpoint of wildlife conservation. Their control or eradication is therefore of mutual advantage to malaria control and wildlife conservation interests. In some instances, aquatic plants may be valuable from the wildlife standpoint and not objectionable from

the mosquito control standpoint. An example of such a plant is the water shield *(Brasenia schreberi)*. This plant grows in water to considerable depths and is listed as a valuable wildlife food plant but malaria mosquitoes are rarely found associated with it. There are probably very few plants of this type.

Many of the plants which are most valuable for wildlife are the least objectionable to mosquito control. It is therefore desirable from the over-all standpoint to encourage these plants in place of those which have no value to wildlife. Planting of these species may help to get them established on a shore line although once established their continued propagation may best be insured by proper water level and other management practices. In general, it is better to use plants which are native to the area rather than to introduce exotic species. Careful study should be given to all plants of this type in order that lists may be developed of species which are most suitable for wildlife planting in a given reservoir. The location of plantings and the species to be planted should be subject to review and approval by the malaria control staff. It is also important to develop a list of those species which should not be planted since once a species becomes established, its eradication may be a difficult and costly operation. Tables 38 and 39 list some of the wildlife food plants approved for planting in the reservoirs of the Tennessee Valley and also some of those which are mutually objectionable to malaria control and wildlife conservation. It should be emphasized that such lists should be developed for a particular reservoir or group of reservoirs only after careful and adequate study of local conditions.

TABLE 38.—Wildfowl food plants approved for planting in reservoirs in the Tennessee Valley.

Common Name	*Scientific Name*
Watershield	*Brasenia schreberi*
Redroot sedge	*Cyperus erythrorhizos*
Chufa	*Cyperus esculentus*
Wild millet	*Echinochloa crus-galli* (Except white-seeded variety)
Midget spikerush	*Eleocharis acicularis*
Spikerushes	*Eleocharis obtusa* and *E. engelmanni*
Squarestem spikerush	*Eleocharis quadrangulata*
Teal grass	*Eragrostis hypnoides*
Rice cut grasses	*Leersia oryzoides* and *L. lenticularis*
Southern naiad	*Najas guadalupensis*
Spiny naiad	*Najas minor*
Hornwort	*Ceratophyllum demersum*
Water buttercup	*Ranunculus circinatus*
Swamp smartweed	*Polygonum hydropiperoides*
Nodding smartweed	*Polygonum lapathifolium*

Common Name	*Scientific Name*
Largeseed smartweed	*Polygonum pennsylvanicum*
Sago pondweed	*Potamogeton pectinatus*
Pondweeds	*Potamogeton diversifolius* and *P. americanus*
Three-square bulrush	*Scirpus americanus*
Southern bulrush	*Scirpus californicus*
Slender bulrush	*Scirpus heterochaetus*
Bluestem bulrush	*Scirpus validus*
Water celery	*Vallisneria americana*

TABLE 39.—Plants found undesirable for both malaria control and wildlife conservation in reservoirs in the Tennessee Valley

Common Name	*Scientific Name*
Alligatorweed	*Alternanthera philoxeroides*
Water primrose	*Jussiaea diffusa*
Water hyacinth	*Eichhornia crassipes*
Lotus	*Nelumbo pentapetala* and *N. nucifera*
Yellow cowlily	*Nuphar advena*
Water chestnut	*Trapa natans*
Giant cut-grass	*Zizaniopsis miliacea*
Cattail	*Typha latifolia*
Juncus	*Juncus effusus*
Willowweed	*Justicia americana*
Wool grass	*Scirpus cyperinus*
Lizardtail	*Saururus cernuus*
Willow	*Salix nigra*
Buttonball	*Cephalanthus occidentalis*
Trumpet vine	*Campsis radicans*

APPLICATION OF LARVICIDES

In selecting larvicides for use in controlling malaria mosquitoes, consideration should be given to the effect of these larvicides upon waterfowl, fish, or fish food organisms. Some larvicidal oils are objectionable, particularly if applied in excessive dosages. Ordinary fuel oil or kerosene does not appear to harm wildlife if applied in average dosages although some destruction of aquatic organisms such as amphipods may result. Careful studies indicate that paris green applied at rates of 1 to 2 pounds per acre has no deleterious effect upon fish or fish food organisms, being almost specific for *Anopheles* mosquito larvae. Formulations of the new insecticide, DDT, have been found to be quite toxic to fish and other aquatic organisms if applied as oil solutions or emulsions, particularly if the dosage is in excess of 0.25 pound of DDT per acre. However, a 20 percent solution of DDT in tetramethyl naphthalene has been found to produce no significant injury to fish and fish food organisms when applied by airplane as a thermal aerosol at rates of 0.1

pound or less of DDT per acre with recovery rates of approximately 0.01 pound per acre. At these rates of application, the material does destroy certain surface Hemiptera and some adult flies but does not significantly decrease the over-all production of fish food organisms or show any deleterious effect upon fishes. The effect upon wildlife of other methods of applying DDT should be carefully investigated before being adopted for wide-scale or routine use.

PERMANENT MARGINAL MEASURES

During recent years, there has been an increased tendency to utilize measures such as filling, dewatering, or land-use restrictions to daytime occupancy to eliminate permanently the malaria hazard from problem areas of reservoirs. Fill areas might in some instances be objectionable from the standpoint of fisheries management because they reduce the area of fish production. However, this is not always true since in many instances their construction involves both deepening and filling rather than merely filling. Also, the same areas may in some instances be utilized for the production of marginal wildfowl food plants. Diking and dewatering areas may often be used to great advantage in the development of waterfowl resources. These areas are kept dewatered during the summer mosquito-breeding season and may be managed to produce extensive stands of waterfowl food plants. If located on flyways of migratory waterfowl, they may be reflooded at the end of the mosquito-breeding season in order to provide feeding and resting grounds for these migrating waterfowl. The production of wildfowl food in the area may sometimes be increased by planting or by agricultural share cropping of corn and other crops.

In some instances, areas in which land use is restricted to daytime occupancy as a means of preventing malaria transmission, an opportunity is provided for the development of wildlife refuges both for waterfowl and upland game. In such areas, it will be possible to develop permanent lateral ponds in connection with muskrat and other wildlife developments without interfering with malaria control interests. One disadvantage in such areas is that mosquito control shore-line conditioning operations are not carried out, and it is therefore necessary for wildlfe interests to provide for control of coppice and other objectionable plants in order to realize the maximum production of marginal wildlife food plants.

XV. PERSONNEL TRAINING AND PUBLIC RELATIONS

Adequate training of personnel engaged in malaria control, and cooperation of those who are to benefit from malaria control, are essential to maximum effectiveness of control activities. The early establishment of a training program will greatly facilitate both preimpoundage and postimpoundage field operations. It is the direct responsibility of the engineer in charge to institute training programs for personnel under his supervision. The establishment of relationships to secure public cooperation in malaria control activities is also an interest of the engineer. Establishing such relationships, however, can usually be accomplished more easily by working through the local or State health departments since they usually maintain procedures and channels for the dissemination of health information to the public. Specific information relative to personnel training programs and to securing good public relations is presented in this chapter.

PERSONNEL TRAINING

Training is an integral part of any malaria control program. The efficiency and effectiveness of operations will depend upon how well the worker has been trained for his job. Equipment and materials are no better than the workman who uses them. The need for training extends to all personnel from supervisors to the lowest grade laborers. Many of the jobs are relatively simple but it cannot be assumed that the simple jobs will be performed correctly merely by giving the workman tools and telling him what you expect him to do. For example, routine entomological inspection is simple, but the inspector must understand why he is doing his job and how and where to look for larvae and adult mosquitoes. Larviciding is also a relatively simple procedure, but if both supervisory personnel and workers are not properly trained, materials and effort will be wasted in an inefficient and ineffective operation.

In general, people do what they know how to do. They learn proper techniques only when those techniques are properly taught to them. Without proper training they will learn only through experimentation and error which is a slow and inefficient process, and even then they may learn incorrectly. Time is always gained and efficiency increased when personnel are adequately trained before a job is started.

In addition to specific job instruction, general orientation and

training are also necessary. Every individual should know how his job fits into the over-all program, and he should understand its importance in protecting the health and welfare of the community. With this understanding, his job will be performed better because the worker can feel that he is contributing to the performance of a big job rather than merely doing a menial task.

If the worker is properly oriented in his job, he will also do much to further good public relations and general understanding of the program. Every worker has many opportunities to explain to his family and friends what he is doing and why he is doing it. A well-informed operational crew will do much to obviate many problems in public relations which might otherwise arise from a lack of public understanding. It is usually assumed that personnel training is applicable only to new employees who are undertaking a new job, but adequate personnel training should also include refresher courses for continuous improvement of skills and efficiency of all personnel by keeping them abreast of improvements in techniques.

General orientation

General orientation should be adapted to the various types of workers who are being trained. This phase of training should include the general aspects of malaria and its prevention. An outline of subject matter is given below as a suggestion of what should be included.

1. Malaria as a disease:
   (a) Epidemiology and clinical manifestations.
2. The biological basis of the malaria problem.
3. The malaria parasite:
   (a) Life cycle and method of detection in man and the mosquito.
4. The malaria vector:
   (a) Life cycle and habits.
5. Control measures:
   (a) Elimination of mosquito-breeding places.
   (b) Larviciding and other antilarval measures.
   (c) Adult mosquito destruction.
   (d) Mosquito-proofing and other protective measures.
   (e) Parasite destruction.
   (f) Education.
   (g) Naturalistic control measures.
6. The malaria problem as it is related to the specific situation of the area in which the program is being operated.

The length of time required for presentation of this subject matter will vary from a few hours to several days, depending upon the extent to which the subject matter is discussed. Audio-visual aids and general discussions are likely to be the most effective way of presenting information during the general orientation period. General orientation should also include an acquaintance with the organization and administrative aspects of the program for personnel at the supervisory level.

Specific job instruction

Specific job instruction is needed for all operational personnel and should follow the period of general orientation. In order to instruct an individual in the various aspects of a specific job it is necessary that the job be broken down into its various components. The responsibility of the instructor in specific job instruction is great. His mistakes may be multiplied many times and can therefore be very costly in manpower and materials. The instructor should understand his responsibility, should have an interest in training, and should have a thorough knowledge of the job and subject matter that he is to teach. Proper methods will increase the effectiveness of his instruction. He should not trust his memory on various points of the job he is to teach. The principal steps of the job should be listed, and key points should be indicated so that proper emphasis can be given to various aspects of the work.

Teaching techniques

Every applicable technique should be employed that will increase the speed and effectiveness of the training procedure. Lectures, demonstrations, quizzes, discussions, audio-visual aids, supervised practice, and other teaching techniques may be utilized. Judgment must be exercised in choosing the most applicable teaching procedures. In general, lectures are the least effective. There are very few individuals who are capable of using the lecture technique with great success. Discussions in which the group participates are far more effective. Quizzes are very useful both to the instructor and the trainee. They help in clarifying points which may be misunderstood by the class. They also assist in focusing attention on key points.

The job instructor's training course which was developed during World War I, and which was widely used during World War II for rapid training of military and industrial personnel, sets forth very clearly some important steps to be followed in specific job instruction.

HOW TO GET READY TO INSTRUCT

Have a time table—how much skill you expect him to have and how soon.
Break down the job—list principal steps, pick out key points.
Have everything ready—the right tools, equipment, and materials.
Have the work place properly arranged—just as the worker will be expected to keep it.

HOW TO INSTRUCT

STEP 1. *Prepare the worker.*
Put him at ease.
Find out what he already knows about the job.
Get him interested in learning the job.
Place in correct position.

STEP 2. *Present the operation.*
Tell, show, illustrate, and question carefully and patiently.
Stress key points.
Instruct clearly and completely, taking up one point at a time—but no more than he can master.

STEP 3. *Try out performance.*
Test him by having him perform job.
Have him *tell* and *show* you; have him explain the key points.
Ask questions and correct errors.
Continue until you know HE knows.

STEP 4. *Follow up.*
Put him on his own.
Check frequently. Designate to whom he goes for help.
Encourage questions. Get him to look for key points as he progresses.
Taper off extra coaching with close follow-up.

Training aids

Training aids such as lantern slides, silent and sound film strips, and motion pictures, are very valuable adjuncts both in personnel training and public education. The function of audio-visual aids is not to replace other methods and mediums but to supplement the written and spoken word and enable the audience to get a much clearer concept of the subject matter being presented. Discussions, demonstrations, reading, practice, quizzing, and other applicable methods are irreplaceable and together with audio-visual aids constitute the tools to be used by the instructor.

Proper use of audio-visual aids requires preparation. The following points have been found to increase greatly their effectiveness:

1. The film or other material should be selected to suit the audience and purpose for which it is intended.

2. The instructor should be thoroughly familiar with the material that he is to use.

3. Guides for the use of the material should be carefully read and followed since they are designed to increase effectiveness.

4. Before use, the material should be discussed and its purpose and content given.
5. A brief resumé of the subject matter should be presented.
6. Discussion should be held to clear up misunderstandings.

The material may be reviewed several times, stopping for discussion whenever it is necessary, and review should be repeated and discussion held until all points are understood by the class. Make sure that the key points stick.

Field demonstration and supervised practice

There is no substitute for field demonstration and supervised practice. The primary purpose of other techniques is to enable the trainee to get a quicker grasp of the job. When he is ready for field training—

1. An area should be selected where all phases of the job can be performed.
2. The instructor should see that correct materials and equipment are on hand.
3. He should carefully demonstrate proper procedures and techniques doing the job so that each worker can see what is being done.
4. The trainees should be allowed to repeat these same procedures while under the observation of the instructor.
5. The instructor should take the opportunity to answer questions and correct errors which are being made by the trainees.
6. Supervised practice should be continued for as long as is necessary for the worker to understand the job he is to perform.

In general, it is safe to assume that if the worker has not learned, the instructor has not taught, for the efficiency of each worker depends to a large extent upon how well he has been trained. Poor work reflects poor training. The instructor's responsibility is great, and much depends on him for the over-all efficiency and effectiveness of the operational program.

PUBLIC RELATIONS

To be of maximum effectiveness malaria control must be understood and supported by the people for whom protection is provided. Much of the protective value of these measures arises out of their intelligent use by people. An educational program which combines the efforts of various interests in the interpretation of malaria control to the public will enhance the effectiveness of the control program. Citizens informed on malaria and control measures for

preventing its transmission will be more likely to mosquito-proof their houses and stay within them during the hours after dusk, to use insecticides against adult mosquitoes, to exert initiative in eliminating and controlling mosquito breeding on small ponds and other possible breeding areas near their dwellings, and to make proper use of medical care. Persons who know why blood smear surveys are made and what the results of these surveys show will be more likely to cooperate in them.

For the public to be informed about malaria transmission and measures for its prevention, they must have specific facts and instruction which should result in the development of sound habits, practices, and attitudes. These things do not result from chance any more than do correct operational procedures but occur as the result of a planned effort to supply facts and instruction. Good public relations do not result merely because someone tells people that a malaria control program is good for them. They need to understand what malaria control is and how they can benefit from it. Public relations personnel should have an interest in their job, should have enough background and knowledge of malaria and its control and of adult educational techniques to use judgment in when, where, what, and how to present the subject effectively.

Reaching the public

There are many channels through which segments of the general public in any given area can be reached. Health agencies have established procedures and channels for reaching the public on matters affecting the public health and will usually take the lead in malaria educational programs. Impounded water owners will benefit from participation in malaria educational programs undertaken by the health departments about their impoundages. If necessary or desirable, health departments can secure the cooperation of other organizations in establishing training programs in the production or securing of such educational material as films, film strips, booklets or pamphlets, and possibly in supplying help in planning and carrying out educational programs.

A program for securing good public relations, whether carried out by the health department or impounding organizations, will be more likely to succeed if certain principles are followed which already have been tested and found effective.

In reaching the public it is important to work through established organizations and agencies. Practically all areas of a county or State are covered by one or more organizations such as the Agricultural Extension Services with their farmers, homemakers, and 4-H clubs, the Grange, and school organizations. Villages and cities

will have, in addition, civic and other clubs. When such organizations are approached and the program explained to them, they usually are willing to devote a portion of their activities to a discussion of malaria.

Churches, especially in rural areas, frequently allow their buildings to be used for community meetings or will make announcements relative to various matters of public interest from their pulpits at regular church services.

Schools can render service in securing good public relations. Schools should be approached through the school officials. When the program is explained to them and their understanding and cooperation have been secured, the way is cleared to plan with administrators' and teachers' educational activities which can be carried out in the schools. It will probably be necessary for teachers to learn about malaria and its control and to be supplied with instructional material before they can do the necessary teaching.

Utilization of established agencies and organizations to secure good public relations offers several advantages. The public relations worker does not need to spend valuable time organizing numerous community meetings but can reach groups of people through already organized meetings. The majority of the population in any one area, large or small, can be reached. When local leaders are collaborating, the services of newspapers, radio, motion picture projection equipment, mimeographing equipment, etc., can be more readily obtained.

Information presented at meetings can be varied so as to secure understanding participation of people in such phases of control operations as human malaria surveys, anopheline surveys, mosquito-proofing programs, house-spraying programs, elimination of small potential or actual breeding places near homes, schools, churches, hospitals, and other buildings used after dusk.

A variety of methods of reaching people with information should be employed, since learning is enhanced by an interesting presentation of facts. To supplement the spoken and printed word, charts, maps, diagrams, photographs, motion pictures, slides, strip films, and exhibits of what is being talked about are all valuable ways of presenting information to aid in creating a proper attitude.

Examples of ways in which the public may be reached

Many informational programs aimed at securing the cooperation of people living around impoundments have been carried out by the impounding organization in collaboration with the State and local health departments. The impounding organizations assisted the health departments by supplying supplementary funds for the

employment of additional personnel, for securing films, film strips, projection equipment, pamphlets, bulletins, and other teaching aids. The planning and conduct of the programs were cooperatively carried out by specialists from the reservoir organizations and the health department.

State health departments have employed public relations people, or malaria educators as they are sometimes called, assigning them during the malaria season to community education work within the zone of influence of an impounded reservoir. These workers were given a 2-week intensive training period following very much the same outline as indicated in the section, "General Orientation." Subsequently, they carried on a general malaria information program presenting the facts about malaria as a disease, how it is spread, and what people as individuals, as family groups, and as communities can do to control it. Frequently, when some specific point arose concerning the malaria control program of the impounding organization, the engineer in charge of this activity participated in related discussions and explanations.

The persons employed in this community work were usually residents of the locality in which they were to work, and were frequently recruited from school teacher groups. Thus, they were local people familiar with local leaders and organizations. In a number of instances, teachers have developed malaria education projects when they returned to their schools.

In other situations, State health departments have employed public relations personnel to do the preliminary educational work necessary for a particular phase of operations such as residual house-spraying with DDT. This provides the opportunity to inform people not only about the particular control procedure being applied, but about general control activities as well.

Such programs as have been mentioned serve to translate malaria information into action that affects the lives of people. An informational program which interprets all phases of malaria control to the public will not only lighten the task of the staff who are instituting the control measures but will in no small way improve the effectiveness of their efforts.

XVI. SMALL RESERVOIRS

GENERAL

The malaria control principles and procedures discussed in preceding chapters, principally for large impoundments, also apply in general to the smaller types of reservoirs and ponds. However, as the uses and mosquito control problems of small reservoirs generally differ from those of larger impoundments, it may be necessary to modify and adapt, both in scope and detail, certain malaria control procedures employed on large lakes to meet the special requirements of small reservoirs.

The term "small reservoirs" is not intended to imply a precise definition in terms of area. It is rather a practical designation used to distinguish between small artificial lakes or ponds and large flood control, navigation, or power developments. This chapter is concerned for the most part with factors peculiar to those impoundages ranging in size from a fraction of an acre to approximately 100 acres. However, in terms of planning and accomplishing malaria control, size is not nearly so significant as reservoir usage and management. Examples of small reservoirs commonly encountered are small recreation lakes, water supply reservoirs, livestock ponds, and fish and waterfowl ponds.

In the endemic malarious States of the United States small impoundments greatly outnumber large ones (fig. 191 & 192). Some States have several thousand small reservoirs. Frequently, these reservoirs create a considerable malarial potential because of: (1) proximity to population, (2) physical characteristics and uses which produce favorable conditions for malaria mosquito production, and (3) the limited choice of applicable control methods. Many small impoundages still exist which are intimately associated with the malaria histories of certain localities. Records of State Health departments in the Southeast reveal malaria epidemics resulting from the creation of small ponds in communities previously malaria free. In other cases prevailing endemic malaria has been intensified by such projects. During the past 10 years or more the number of small impoundments has increased greatly in the malaria States. This is principally a result of increased interest in recreational developments in the South, and the expansion of cattle grazing (stock ponds), and development of farm fish ponds as a phase of soil conservation programs.

RELATIONSHIP OF MALARIA CONTROL TO VARIOUS TYPES OF SMALL RESERVOIRS

Recreational lakes

Lakes of this type, varying in size from a few acres to 25 or more, are usually built for bathing, boating, and fishing. Physical characteristics and operational features which tend to produce malaria problems on small recreation lakes are:

1. Location within *A. quadrimaculatus* flight range of community.
2. Evening entertainment facilities for adjacent populations.
3. Constant level pool, insufficient inflow for water level management, or lack of water control structures.
4. Location in flat terrain favoring establishment of objectionable marginal growth.
5. Physical and chemical composition of water (frequently spring-fed with high mineral and carbon dioxide content) favoring development of objectionable aquatic plants.

Malaria control practices on recreational lakes may increase their value as such. People will not continue to patronize such places when they are annoyed by mosquitoes; nor will some persons return to places suspected of being a malaria hazard. Bathers are attracted to a lake with a clean water surface but repelled by one overgrown with vegetation or covered with drift and flotage.

Municipal and industrial water supply reservoirs

Frequently, water supply reservoirs incorporate features favoring malaria control. Often these reservoirs are isolated and their watersheds have been cleared of human habitations as a safeguard against pollution and contamination. Complete removal of all vegetation from the entire basin is considered standard practice as well as elimination of shallow areas in which aquatic and semiaquatic plants thrive. The practice of preventing aquatics from becoming established, because of undesirable taste and odor problems, results in provision for adequate maintenance. A clean water surface in this type of reservoir is of equal importance to those responsible for producing a satisfactory drinking water and to those concerned with malaria control.

Frequently, the water-level recession occurring as a result of decreased summer flows may be advantageous for mosquito control.

Some industrial plants have small storage ponds for plant processes or fire protection. In some cases constant level pools are maintained and their use does not require the thorough preparation and control of marginal plants as in the case of municipal water-

FIGURE 191.—Small recreational lake used for fishing and boating. (Note clean shore line and water surface, and the absence of aquatic vegetation.)

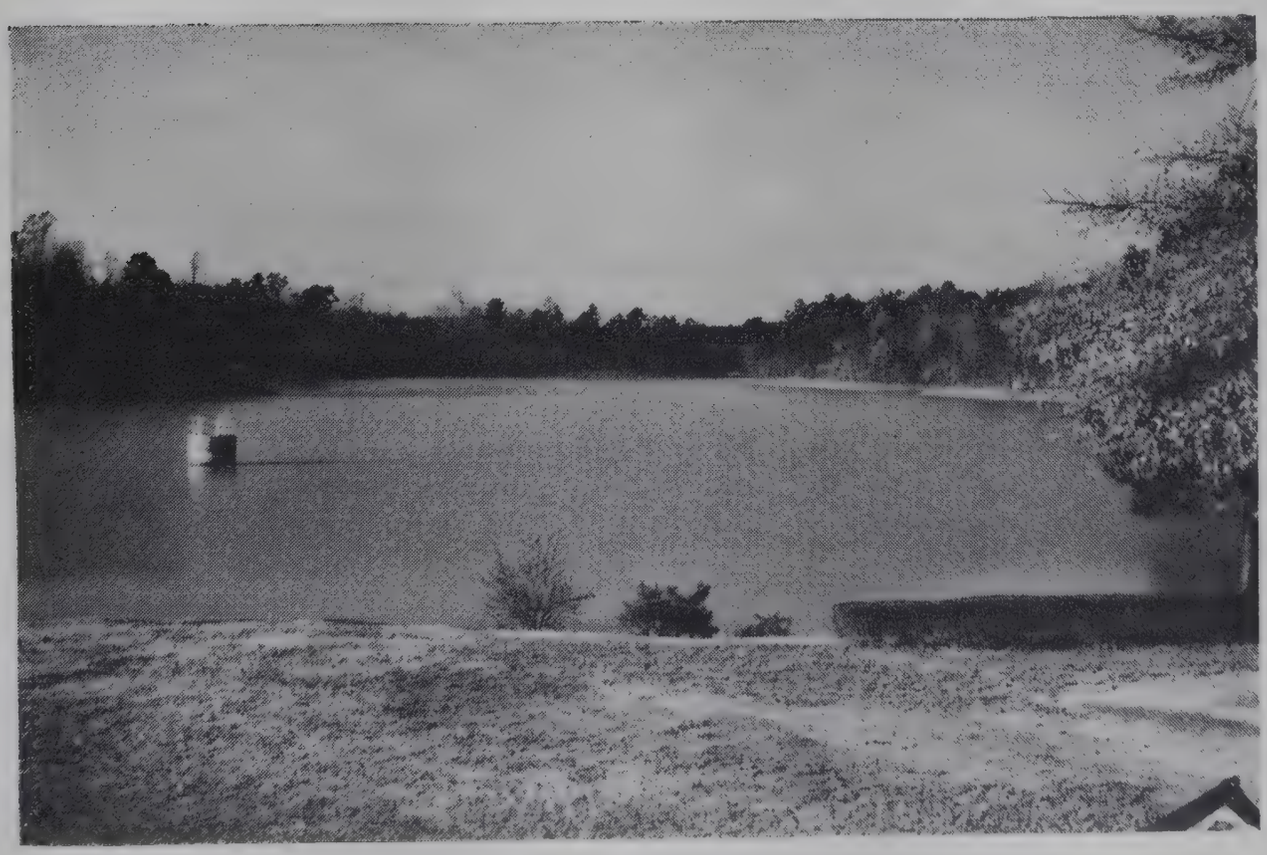

FIGURE 192.—A properly maintained municipal water supply reservoir. (Steep shore lines and deep water usually prevent establishment of objectionable vegetation.)

supply reservoirs. They frequently are neglected and become overgrown with vegetation. Many become hazards or mosquito nuisances in that they are often located close to population centers.

Farm ponds

Agricultural ponds usually consist of an earth dam constructed across a low-flow or intermittent stream with a limited watershed. As a rule they are shallow, constant level pools and are seldom equipped (nor do they have sufficient inflow) to permit water-level fluctuation. Such impoundages, used for watering stock or as farm fishponds, vary in size from the very small (less than one-half acre) to 1 to 5 acres. Their maximum depth as a rule does not exceed 6 to 8 feet. These features, together with their customary proximity to the owner's home, may produce a malaria hazard unless the ponds are cleared and properly maintained for mosquito control.

Fish and wildfowl ponds

Many small ponds are constructed for fish and wildfowl development. Frequently those small impoundments, both privately and publicly owned, have been created and maintained without adequate provision for malaria control. Many have flat, shallow areas with no provision for water level management for mosquito control. Conditions which are unfavorable to both wildlife and malaria interests often develop a short time after impoundage.

For example, uncontrolled vegetation may permit the colonization of undesirable aquatic and semiaquatic plants which are objectionable to mosquito control and which may crowd out those plants which are desirable to wildlife interests. Excessive vegetation hinders fishing and fish culture, and at the same time may favor mosquito breeding. Frequently, after these conditions develop, the pond is abandoned as unsuitable for wildlife purposes and left as a permanent breeding place for malaria mosquitoes.

Increased knowledge and a better understanding in recent years have demonstrated that conflicts between wildlife conservation and malaria control interests are more apparent than real. Moreover, it has been demonstrated that there are many features of water-impoundage management which are of mutual interest as discussed in chapter XIV.

APPLICATION OF STATE REGULATIONS TO SMALL IMPOUNDMENTS

The impounded water regulations of most State health departments apply to all small reservoirs with a water surface greater than

one-half acre, except where they are located more than 1 mile beyond any human habitation other than that of the owner. The limit of one-half acre usually excludes the small stock ponds found on many farms. State regulations, in general, require such basic malaria control measures as clearing, installation of water-level control structures, (i.e., flashboards in the spillway, bottom drains for dewatering the pond, and other control means) , periodic removal of objectionable marginal plants and flotage, and in some instances the introduction of top-feeding minnows.

PLANNING AND SELECTION OF SITE FOR SMALL RESERVOIRS

It is desirable in the interest of effectiveness and economy that malaria-control measures be incorporated and coordinated with other plans for use of the reservoir. Frequently it will be possible to insure adequate mosquito control without interfering with its primary purpose or increasing the operational cost of the reservoir. Primary considerations in planning malaria control on small reservoirs are location and topography, size, stream flow, water control structures and appurtenances, and character of soil.

In the selection of a site for a reservoir, consideration should be given to the topography of the area and proximity of human habitation. In some instances it may be possible to locate fish and wildfowl ponds a mile or more from any residence. Topographic conditions preferably should be selected which will result in a lake with relatively steep shore lines and deep water rather than flat, shallow marginal areas. Narrow valleys in steep topography are the most desirable sites for malaria control and are usually most suitable for dam construction. The topography also affects the area of the water surface and has a bearing on the mosquito breeding potential and the amount of maintenance required for mosquito control. Obviously, a larger pond should not be constructed than is necessary to meet the objectives of the project.

In planning water level schedules for malaria control and other operations it is necessary to consider stream flow and the necessary control structures and appurtenances. Plans should include installation of a bottom drain of adequate size and a spillway structure in which flashboards may be operated to raise and lower the water level.

An accurate topographical map of the reservoir site and data pertinent to its operation are desirable for initial malaria control planning. If these are not available, a simple plan map should be made that will provide such basic information as (1) over-all dimensions of the lake and extent of shallow water areas, (2) location and size of

drain, (3) location and features of spillway, and (4) the area covered by the lake at high and low pool levels.

In appraising the potentialities of malaria transmission for a proposed reservoir, it is advisable to determine the location and number of human dwellings within 1 mile of the ponded water and any other nearby existing ponds and situations which may produce mosquitoes. An investigation of these or other old reservoirs in the region will furnish valuable information for estimating the mosquito potential and planning control operations for the proposed reservoir.

CONTROL MEASURES

Unless the reservoir is more than 1 mile from human habitation, it will be necessary to make provision for adequate anopheline mosquito control through proper preparation of the reservoir, water level management, shore-line maintenance, and the use of larvicides, if necessary.

Reservoir preparation

A principal requirement of proper reservoir preparation is the removal of all trees, logs, brush, and vegetation within the pool area. This is necessary to prevent conditions which would otherwise be favorable for the production of anopheline mosquitoes. Whenever possible it is desirable that the trees in the fluctuation zone be cut close to the ground in order to facilitate future shore-line maintenance operations. Extensive clearing beyond the pool level is not necessary but a cleared strip extending 5 to 10 feet landward is desirable.

Proper reservoir preparation should also include drainage of any marginal depressions or marshy areas in order that the water therein will drain out or fluctuate with the main pool.

A detailed discussion of reservoir clearing and drainage is given in chapter III.

On some small reservoirs, steepening of the shore line and elimination of shallow water areas by deepening and filling will reduce or eliminate habitats favorable to malaria mosquitoes by: *(a)* facilitating control of objectionable vegetation; *(b)* increasing effectiveness of wave action; *(c)* decreasing the area favorable to collection of drift and flotage; and *(d)* reducing the reservoir maintenance problem.

Such shore-line alterations may be accomplished either by manual or machine methods, depending on the amount of earth moving involved. On some very small ponds a plow and team scraper can be used effectively. Drag pans, bulldozers, draglines or scrapers may be used on larger jobs. Steepening the shore line and the elimination of shallow areas can usually be done simultaneously; that is, spoil from

the shallow areas being deepened may be used to fill the shallow area nearest the shore and to form a new steeper shore line (figs. 43 and 84). When this is not possible, the shallow water areas can be filled with earth selected and worked in such a way as to prevent formation of another mosquito breeding place. A more detailed discussion of deepening and filling and minor shore line topography alteration is given under "Deepening and Filling" in chapter IV and "Minor Shore Line Topography Alteration" in chapter VI. Such operations can usually best be carried out during construction of the project when suitable earth-moving equipment such as bulldozers and graders is available.

Adequate reservoir preparation will minimize the mosquito production, increase the effectiveness of water level management, and reduce the shore-line maintenance operations and costs. In many reservoirs the maintenance of a clean water surface through reservoir preparation and shore-line maintenance, coupled with favorable water management, will eliminate the need for application of larvicides.

Water level management

Water level management, sometimes referred to as water level fluctuation, can be utilized to great advantage in mosquito control on impounded waters. A full discussion of the basic principles and various phases of this measure is given in chapter V as it applies principally to major reservoirs on large streams. Some of the phases can be applied on small impoundages if satisfactory water control structures are provided. The extent and type of water management utilized is dependent on the size of the reservoir, water inflow, operation, primary use of the reservoir, and available personnel for regular manipulation of the water control structures.

There are several phases of water level management which may be used singly or in combination for mosquito control. They are:

1. Flood surcharge
2. Constant level pool
3. Periodic fluctuation
4. Seasonal recession

Of these phases, use of the flood surcharge, constant level pool, and seasonal recession are usually most adaptable to small impoundages.

In small reservoirs a flood surcharge of 1 to 2 feet can be used to strand objectionable flotage. It is usually employed during the winter or early spring prior to the mosquito-breeding season at any convenient time there is sufficient rainfall and stream flow. A flood surcharge used for only a day or so will effectively strand the flotage. To effect a

flood surcharge, it is necessary for the dam to have the necessary freeboard and removable flashboards in the spillway or other means for raising the water level.

The next phase, a constant level pool, is one which can be applied to almost all small impoundages. It consists of bringing the water level to the normal top pool elevation and holding it at a constant level throughout the spring growth period in order to limit the invasion of marginal wetland plants. This phase is especially important since it will increase the effectiveness of subsequent fluctuation or recession. The constant level pool phase is of special interest in fish ponds or hatcheries as spawning occurs during the usual period of its use.

By periodically raising and lowering the pool level (fluctuation) at weekly or 10-day intervals mosquito larvae can be stranded or exposed to natural predators. To be effective, the scope of the fluctuation should be about 1 foot. In actual practice, the scope and period of the fluctuation cycle will be dependent on the inflow. If this is limited a longer cyclical period will be beneficial; however, a period longer than 2 weeks has the disadvantage of permitting a faster rate of marginal growth invasion. Periodic water level fluctuation and recession should be instituted shortly after the malaria mosquito breeding season begins. (See ch. XI.) From a practical standpoint, water-level fluctuation may best be accomplished through the manipulation of stop-logs or flashboards installed in the spillway or other water control structure (figs. 193 and 194). The procedure commonly used to effect fluctuation is to remove and replace alternately the flashboards

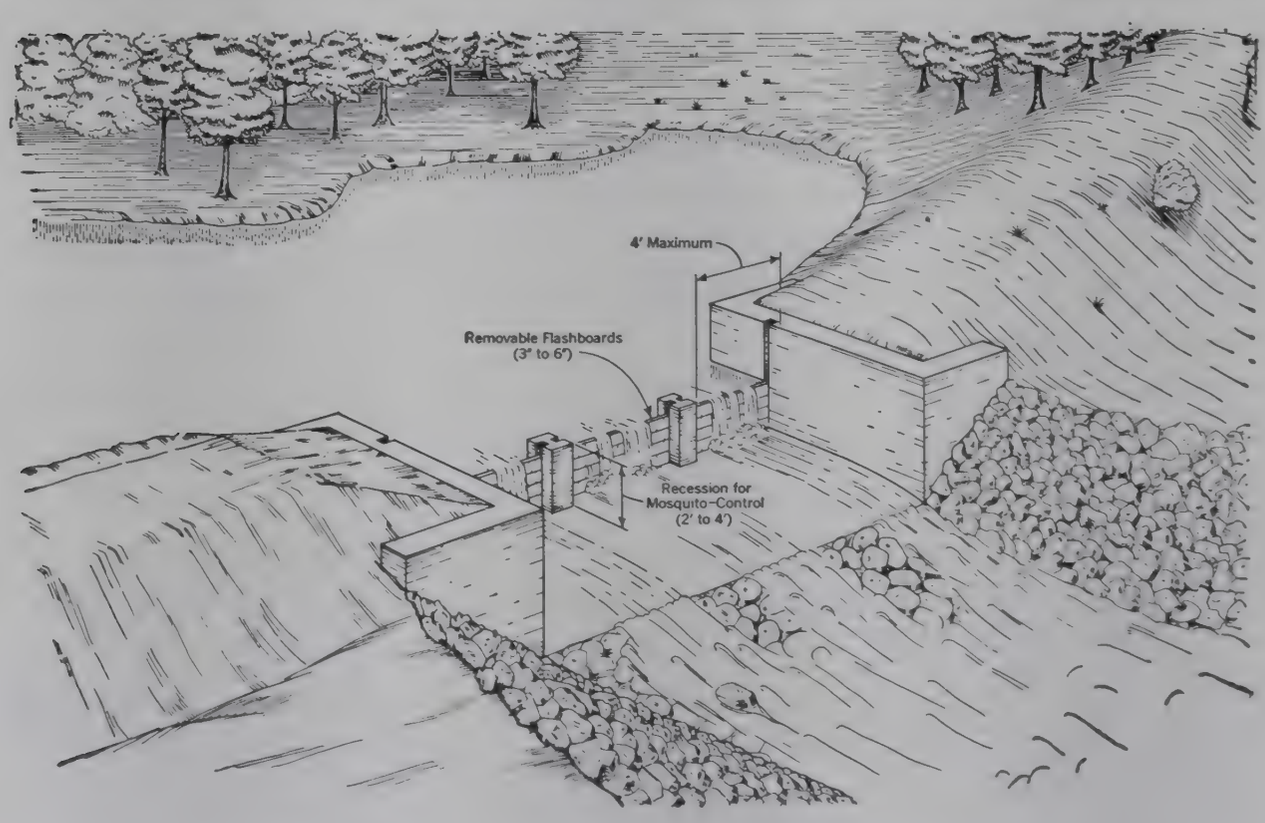

FIGURE 193.—Flashboards installed in a concrete spillway.

at 4- or 5-day intervals. When flashboards are installed in the main spillway there should be sufficient spillway capacity above the top flashboard to pass the maximum design flood flow.

Most small impoundments are provided with a bottom drain which may be used for fluctuating the pool level provided it is of adequate size and there is necessary attendance. The bottom drain should be of sufficient size, as a minimum, to carry the normal summer flow without impoundage. A vertical extension at the upper end of the drain pipe extending to the water surface may be utilized for fluctuating the water level by the attachment of short sections of pipe which can be alternately removed and replaced. These removable sections of pipe act as a circular spillway and should be of sufficient size to draw off the water within a time interval of 4 to 5 days.

Seasonal water level recession used alone, or in combination with periodic water level fluctuation, is a very effective mosquito control measure as it tends to produce progressively a clean shore line. However, the resulting exposure of the margin does permit the invasion of marginal plants which will normally require removal at the end of the mosquito season.

Recession may be practiced on ponds with insufficient flow to permit fluctuation. It is most effective on impoundages with steep shore lines. The effective recession rate must be determined for each reservoir considering the stream flow, capacity and uses of the reservoir, and rate of plant invasion and mosquito production. In general, assuming the lake to have been properly prepared and adequately maintained, a recession of 1 to 3 inches each week should be

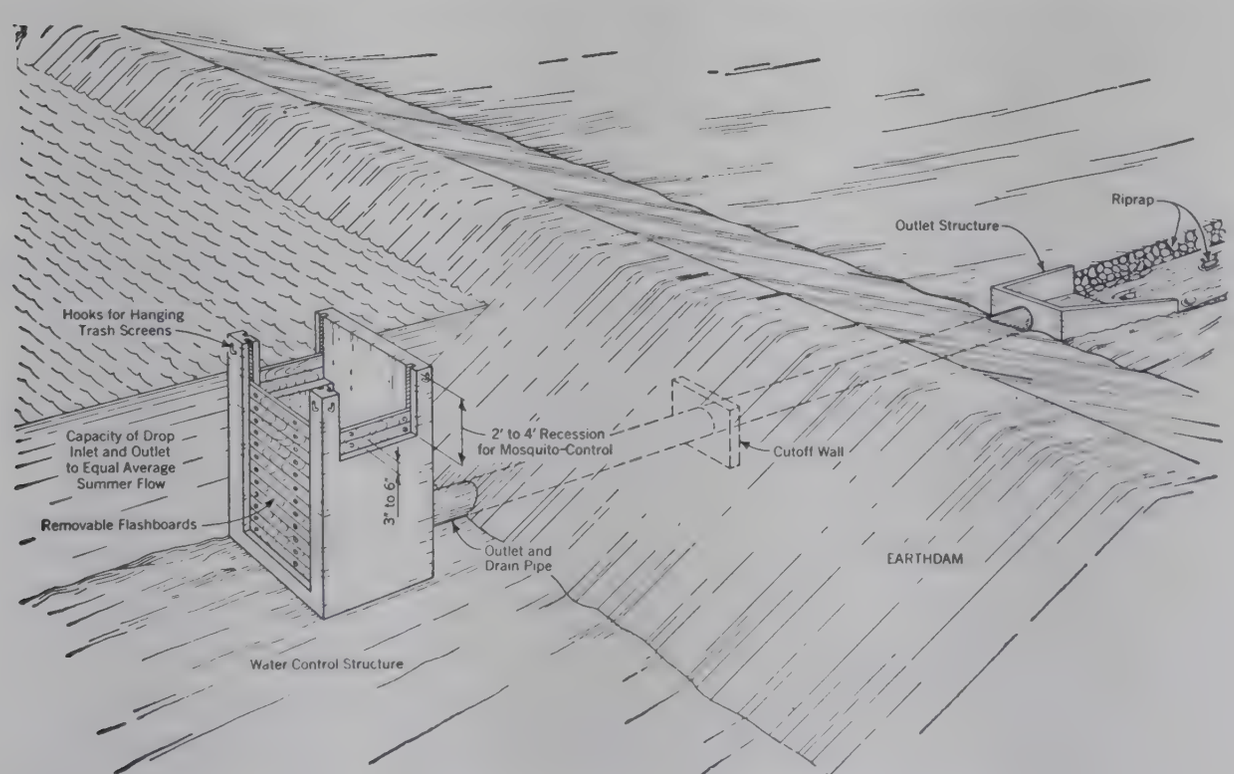

FIGURE 194.—Water control structure with flashboard arrangement.

initiated at the beginning of the malaria mosquito-breeding season. When used with fluctuation it can be initiated later, say around July 1.

When water uses, evaporation, and decreased stream flow are considered, many small reservoirs have a normal recession of 1 to 3 inches per week or more during the summer. When the normal operating recession is not sufficient, recession can usually best be accomplished by removing narrow flashboards in the spillway or water control structure at the required intervals.

Reservoir maintenance

Maintenance on the small reservoir, if it has been planned and properly prepared for malaria control, is largely a job of keeping the shore line free of drift, flotage, and marginal vegetation, and preventing establishment of objectionable plants which will provide a favorable habitat for the malaria vector. Maintenance operations during the summer should consist of weekly inspections and correction of conditions favoring mosquito breeding. On most small impoundments the amount of work required will usually be relatively small and can be done with hand tools. Shore-line maintenance should include removal of debris and drift and objectionable growth prior to the beginning of the mosquito breeding the following season. Reservoir maintenance during the off-season might also include conditioning of the shore line and reservoir so as to minimize seasonal maintenance. This may include minor shore-line alterations such as grading, riprapping, and fencing for marginal grazing.

Adequate reservoir maintenance for malaria control increases the attractiveness and utility of a lake and insures a clean water surface which is of primary importance in malaria control on impounded water. Costly and difficult maintenance results when ponds are neglected, or if they have been constructed without consideration for malaria control.

Methods and procedures for shore-line maintenance are discussed in detail in chapter VI.

Larviciding

For esthetic reasons, larviciding with petroleum oil or other chemicals toxic to mosquito larvae is seldom desirable on small reservoirs. Furthermore, it is a control measure that requires careful execution by experienced personnel, and owners or operators of small impoundments are generally without proper personnel or equipment facilities for carrying out effective, routine larviciding. This measure should be used principally as a temporary or emergency one in the absence of other more applicable controls. The advice and assistance of State and local health departments should be sought in planning

or executing control by larviciding. For details on larviciding, the reader is referred to chapter VII.

Fish predators

Various species of fish are natural enemies of mosquito larvae. In lakes or ponds with clean shore lines, and on which sufficient maintenance is provided to prevent formation of flotage and establishment of plants which form mosquito habitats, top-feeding minnows may be used to supplement other mosquito control measures. Some State health department impoundage regulations require that small reservoirs be stocked with minnows such as *Gambusia* or *Fundulus*. Where top-feeding minnows are not present in the stream which feeds the lake, and it is to be stocked, they should be introduced at a rate of 100 to 200 minnows per acre. These fish may be obtained from nearby streams, ditches, or ponds, or they can be supplied from State or Federal fish hatcheries.

Fertilization

Fertilization[9] is a practical measure for the control of certain kinds of leafy aquatic plants commonly associated with malaria mosquito breeding on small impoundments. These are bottom-attached plants (emergent, floating, or submerged), such as *Potamogeton, Myriophyllum, Ceratophyllum, Chara,* etc. When fertilizer is added to a pond, the population of microscopic algae in the water is greatly increased. This dense growth of algae turns the water green or brown and effectively cuts off the sunlight needed by the coarser plants. Thus, the objectionable vegetation is destroyed and fish food, in the form of minute algae, is added to the reservoir.

This method of pond weed control is not practical on ponds with high discharge or overflow rates; nor will fertilization work successfully where a pond receives flood water during the mosquito-breeding season.

On new ponds, the Alabama Agricultural Experiment Station recommends application of 100 pounds of 6—8—4 (N—P—K) and 10 pounds of nitrate of soda for each acre at the beginning of the warm spring weather and after the spring floods. This dosage should be repeated throughout the growing season whenever the pond water begins to lose its color. The fertilizer can be broadcast from the banks over the shallow areas or applied from a sack carried in a boat as the boat slowly travels over the pond. For old impoundments choked with vegetation, the fertilizer should be applied first in December or January at intervals of 2 to 4 weeks until the pond weeds become covered with filamentous algae (pond scum). The fertilizer should be applied directly to the beds of the plants.

[9] Swingle, H. S., and Smith, E. V., Management of Fish Ponds, Bulletin 254, April, 1942, Agricultural Experiment Station of the Alabama Polytechnic Institute.

APPENDIX A

SUMMARY OF STATE LAWS AND REGULATIONS PERTAINING TO MALARIA CONTROL ON IMPOUNDED WATER[10]

ALABAMA

Any person, corporation, or agency desiring to impound water, or to raise the level of an existing pond, must secure a permit from the State Board of Health. This regulation applies to all ponds and reservoirs except those less than one-tenth acre and those more than 1 mile from human habitation other than that of the owner.

All trees, brush, debris, and similar material within the reservoir which would float or collect flotage on the surface of the water must be removed, burned, or otherwise satisfactorily disposed of prior to impounding the water. Vegetation, brush, trees, stumps, etc., which will be permanently and completely submerged at time of low water need not be removed.

All trees and other growth in the reservoir which would pierce the water surface at minimum low water level must be cut off at least 1 foot below such water level to prevent the collection of drift or flotage.

The shore line of the reservoir from minimum low water level to a line at least 15 feet landward from the normal high water level must be cleared of all brush, trees, and other material which might cause the collection of drift or flotage.

All depressions which will be filled with water from the reservoir at times of maximum water level and which will retain water at lower stages of the reservoir must be connected with the reservoir so as to insure complete drainage or fluctuation of the water within the depression.

A bottom drain must be installed in the dam for the purpose of dewatering the reservoir.

The validity of the permit for impounding water is contingent upon the following:

> During the mosquito-breeding season all flotage and debris that create conditions favorable for the production of mosquitoes within 1 mile of human habitation must be kept regularly and frequently removed. Prompt and proper measures must be taken to prevent the growth of cattails, bulrushes, and other

[10] One or more of the provisions of these regulations may be waived in whole or in part when, in the opinion of the State Board of Health, there are factors or circumstances which render compliance with such provisions unnecessary.

aquatic or semiaquatic vegetation which create favorable mosquito-breeding conditions.

After the water is impounded, representatives of the State Board of Health shall make occasional inspections, and any conditions found to be detrimental to public health, or likely to cause an increase of malaria, shall be remedied to the satisfaction of the State Board of Health.

ARKANSAS

Any person, corporation, or agency desiring to impound water, or to raise the level of existing impounded water, must obtain approval for the impounding of such water from the State Health Officer. This requirement does not apply to bodies of water less than one-half acre of water surface and impounded waters more than 1 mile from human habitation other than that of the owner.

All trees, brush, debris, and similar material within the reservoir which would float or collect flotage on the surface of the water must be removed, burned, or otherwise satisfactorily disposed of prior to impounding the water. Vegetation, brush, trees, stumps, etc., which will be permanently and completely submerged at time of low water need not be removed.

All trees and other growth in the reservoir which would pierce the water surface at minimum low-water level must be cut off at least 1 foot below such water level to prevent the collection of drift or flotage.

The shore line of the reservoir from minimum low water level to a line at least 15 feet horizontally landward from the normal high water level must be cleared of all brush, trees, and other material which might cause the collection of drift or flotage, except when exempted by the State Health Officer.

All depressions which will be filled with water from the reservoir at times of maximum water level and which will retain water at lower stages of the reservoir must be connected with the reservoir so as to insure complete drainage or fluctuation of the water within the depression.

Bottom drains or other means must be incorporated in the dam which will permit fluctuation of water level and drainage of the reservoir.

The continuance of the approval for the impounded water is contingent upon the application of control measures satisfactory to the State Health Officer. Control measures may include one or more of the following: Fluctuation of water level, removal of drift and

flotage, stocking with top minnows, removal of aquatic vegetation or other growth, application of larvicides, screening, or any other measures effective in the control of malaria.

FLORIDA

Any person, corporation, or agency desiring to impound water, to raise the level of an existing pond, or to reimpound water must secure a permit from the State Board of Health. This regulation applies to all ponds and reservoirs except those less than one-tenth acre and more than 1 mile from human habitation other than that of the owner.

All trees, brush, debris, and similar material within the reservoir which would float or collect flotage on the surface of the water must be removed, burned or otherwise satisfactorily disposed of prior to impounding the water. Vegetation, brush, trees, stumps, etc., which will be permanently and completely submerged at time of low water need not be removed.

All trees and other growth in the reservoir which would pierce the water surface at minimum low water level must be cut off at least 1 foot below such water level to prevent the collection of drift or flotage.

The shore line of the reservoir from minimum low water level to an elevation of 1 foot above normal high water level must be cleared of all brush, trees, and other material so as to prevent the collection of drift and flotage along the shore.

Flashboards or other means must be provided for controlling fluctuation of the water level at any season of the year.

Bottom drains or other means must be provided which will permit removal of the impounded water.

All depressions which will be filled with water from the reservoir at times of maximum water level and which will retain water at lower stages of the reservoir must be connected with the reservoir so as to insure complete drainage or fluctuation of the water within the depression.

The validity of the permit for impounding water is contingent upon the following:

> During the mosquito-breeding season all flotage and debris that create conditions favorable for the production of mosquitoes within 1 mile of human habitation must be kept regularly and frequently removed. Larvicides must also be applied to all mosquito-breeding areas of the reservoir whenever necessary to control adequately the production of *Anopheles* mosquitoes. Prompt and proper measures must also be taken to prevent the

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growth of cattails, bulrushes, and other aquatic or semiaquatic vegetation which create favorable mosquito-breeding conditions.

After the water is impounded, representatives of the State Board of Health may make occasional inspections, and any conditions found to be detrimental to public health, or likely to cause an increase of malaria, shall be remedied to the satisfaction of the State Board of Health.

GEORGIA

Any person, corporation, or local, State, Federal, or private agency desiring to impound water, or to raise the level of an existing pond, must secure a permit from the State Board of Health. This regulation does not apply to ponds of less than one-tenth acre for watering stock or other domestic purposes, nor to impoundments all portions of which are more than 1 mile from any human habitation, congregation, or place of business other than that of the owner.

All trees, brush, debris, and similar material within the reservoir which would float or collect flotage on the surface of the water must be removed, burned, or otherwise satisfactorily disposed of prior to impounding the water. Vegetation, brush, trees, stumps, etc., which will be permanently and completely submerged at time of low water need not be removed.

All trees and other growth in the reservoir which would pierce the water surface at minimum low water level must be cut off at least 1 foot below such water level to prevent the collection of drift or flotage.

All depressions which will be filled with water from the reservoir at times of maximum water level and which will retain water at lower stages of the reservoir must be connected with the reservoir so as to insure complete drainage or fluctuation of the water within the depression.

The validity of the permit for impounding water is contingent upon the following:

During the mosquito-breeding season all flotage and debris that create conditions favorable for the production of mosquitoes within 1 mile of human habitation must be kept regularly and frequently removed. Larvicides must also be applied to all mosquito-breeding areas of the reservoir whenever necessary to control adequately the production of *Anopheles* mosquitoes. Prompt and proper measures must also be taken to prevent the growth of cattails, bulrushes, and other aquatic or semiaquatic vegetation which offers protection to *Anopheles* larvae.

After the water is impounded, representatives of the State

Board of Health shall make occasional inspections, and any conditions found to be detrimental to public health, or likely to cause an increase of malaria, shall be remedied to the satisfaction of the State Board of Health.

LOUISIANA

Any person, corporation, or agency desiring to impound water, or to raise the level of an existing impoundment, must secure a permit from the State Board of Health. This regulation applies to any impoundment except those less than one-half acre which are used exclusively for domestic purposes.

All trees, brush, debris, and similar material within the reservoir which would float or collect flotage on the surface of the water must be removed, burned, or otherwise satisfactorily disposed of prior to impounding the water. Vegetation, brush, trees, stumps, etc., which will be permanently and completely submerged at time of low water need not be removed.

All trees and other growth in the reservoir which would pierce the water surface at minimum low water level must be cut off at least 1 foot below such water level to prevent the collection of drift or flotage.

The shore line of the reservoir from minimum low water level to a line at least 15 feet landward the normal high water level must be cleared of all brush, trees, and other material which might cause the collection of drift and flotage.

All depressions which will be filled with water from the reservoir at times of maximum water level and which will retain water at lower stages of the reservoir must be connected with the reservoir so as to insure complete drainage or fluctuation of the water within the depression.

Flashboards or other means of controlling fluctuation of the water level must be provided in the design and construction of the project.

Bottom drains or other means must be provided which will permit removal of the impounded water.

Initial filling of the reservoir must not be begun during the malaria mosquito-breeding season (May to October) unless authorized by the State Board of Health.

The validity of the permit for impounding water is contingent upon the following:

> During the mosquito-breeding season all flotage and debris that create conditions favorable for the production of mosquitoes within 1 mile of human habitation must be kept regularly and frequently removed.

A clear shore line must be maintained during the mosquito-breeding season by proper water level management or, where this measure is inadequate, by the removal of brush, drift, and flotage from the shore line as may be designated by the State Health Officer.

Prompt and proper measures must be taken to prevent the growth of cattails, bulrushes, and other aquatic vegetation which create favorable mosquito-breeding conditions.

Where these various methods of larvae control are ineffective or insufficient, larviciding must be carried on as directed by the State Board of Health.

After the water is impounded, representatives of the State Board of Health may make occasional inspections, and any conditions found to be detrimental to public health or likely to cause an increase of malaria shall be remedied to the satisfaction of the State Board of Health.

MISSISSIPPI

Any person, corporation, or agency desiring to impound water, or to raise the level of an existing pond, must secure a permit from the State Board of Health. This regulation applies to all ponds and reservoirs except those less than one-half acre and more than 1 mile from human habitation other than that of the owner.

All trees, brush, debris, and similar material within the reservoir which would float or collect flotage on the surface of the water must be removed, burned, or otherwise satisfactorily disposed of prior to impounding the water. Vegetation, brush, trees, stumps, etc., which will be permanently and completely submerged at time of low water need not be removed.

All trees and other growth in the reservoir which would pierce the water surface at minimum low water level must be cut off at least 1 foot below such water level to prevent the collection of drift or flotage.

The shore line of the reservoir from minimum low water level to a line at least 15 feet landward from the normal high water level must be cleared of all brush, trees, and other material which might cause the collection of drift or flotage.

All depressions which will be filled with water from the reservoir at times of maximum water level and which will retain water at lower stages of the reservoir must be connected with the reservoir so as to insure complete drainage or fluctuation of the water within the depression.

Flashboards or other means must be provided for controlling fluctuation of the water level at any season of the year.

Bottom drains or other means must be provided for reservoirs less than 25 acres which will permit removal of the impounded water.

The reservoir must not be filled during the breeding season of the malaria-carrying mosquito, namely, April to September inclusive, unless authorized by the State Board of Health.

The validity of the permit for impounding water is contingent upon the following:

> During the mosquito-breeding season all flotage and debris that create conditions favorable for the production of mosquitoes within 1 mile of human habitation must be kept regularly and frequently removed. Control measures approved by the State Board of Health or the United States Public Health Service must be applied to all mosquito-breeding areas of the reservoir so as to control adequately the production of *Anopheles* mosquitoes. Prompt and proper measures must also be taken to prevent the growth of cattails, bulrushes, and other aquatic or semiaquatic vegetation which creates favorable mosquito-breeding conditions.
>
> After the water is impounded, representatives of the State Board of Health may make occasional inspections, and any conditions found to be detrimental to public health, or likely to cause an increase of malaria, shall be remedied to the satisfaction of the State Board of Health.

MISSOURI

Any person, corporation, or agency desiring to impound water, or to raise the level of an existing impoundment, must secure a permit from the State Board of Health. This regulation applies to any impoundment except those less than one-fourth acre which are used exclusively for domestic purposes.

All trees, brush, debris, and similar material within the reservoir which might float or collect flotage on the surface of the water must be removed, burned, or otherwise satisfactorily disposed of prior to impounding the water. Trees in shallow areas should be cut as nearly flush with the ground as possible.

Stumps of such trees as willow, cypress, cottonwood, ash, and swamp oak in the zone of fluctuation must be poisoned to prevent sprouting. All underbrush, dead and leaning trees along the shore line must be cleared and satisfactorily disposed of for a distance of 10 feet landward from the high-water contour. In the upper ends of

bights and indentations which are likely to collect drift and flotage the clearing must extend 25 feet landward from the high-water contour. Species of trees which will not stand temporary inundation must be cleared for a landward distance of 25 feet from the top contour.

In flat areas where airplane dusting is anticipated trees which might obstruct flight of the airplanes must be removed and properly disposed of.

All depressions which would become filled at maximum water level and form isolated pools when the water is lowered must be connected with the reservoir by suitable drains and ditches.

Islands subject to erosion must be completely cleared.

Immediately prior to impoundage secondary growth of sprouts and vegetation must be removed between the high- and low-water levels. Sprouts below the low-water contour which would protrude at that elevation should be cut and burned. Any necessary rebrushing in the 10-foot zone above the high water contour must be performed.

Flashboards or other means of controlling fluctuation of the water surface must be provided.

Bottom drains or other means must be provided which will permit removal of the impounded water. These drains or gates must be large enough to lower the level of the impoundment 1 foot in 24 hours.

Initial filling of the reservoir must not be begun during the malaria mosquito-breeding season.

Shore-line maintenance measures, such as may be recommended by the State Board of Health, must be carried out to the satisfaction of that Board.

Larvicidal control measures when deemed necessary to control mosquito breeding must be carried out.

When necessary to control the incidence or transmission of mosquito-borne diseases, other measures of control must be carried out to the satisfaction of the State Board of Health. These measures may include reservoir preparation, fluctuation of the water level, ditching, filling, larviciding, shore-line maintenance, screening, and medication.

The validity of all permits relating to the construction or operation of the impoundment is subject to revocation by the State Board of Health whenever an inspection reveals that the intent of these regulations is not being carried out.

NORTH CAROLINA

Any person, corporation, or agency desiring to impound water, or to raise the level of an existing pool, must secure a permit from the State Board of Health. This regulation applies to all ponds and reservoirs except those less than one-fourth acre.

All trees, brush, debris and similar material within the reservoir which would float or collect flotage on the surface of the water must be removed, burned, or otherwise satisfactorily disposed of prior to impounding the water. Vegetation, brush, trees, stumps, etc., which will be permanently and completely submerged at time of low water need not be removed.

All trees and other growth in the reservoir which would pierce the water surface at minimum low water level must be cut off at least 1 foot below such water level to prevent the collection of drift or flotage.

The shore line of the reservoir from minimum low water level to a line at least 10 feet landward from the normal high-water level measured horizontally must be cleared of all brush, trees, and other material which might cause the collection of drift or flotage, except when specifically exempted by the State Board of Health.

All depressions which will be filled with water from the reservoir at times of maximum water level and which will retain water at lower stages of the reservoir must be connected with the reservoir so as to insure complete drainage or fluctuation of the water within the depression.

Flashboards or other means must be provided for controlling fluctuation of the water level at any season of the year.

Drains or other means must be provided which will permit removal of the impounded water.

The reservoir must not be filled during the breeding season of the malaria-carrying mosquito, namely, April to September inclusive, unless authorized by the State Board of Health.

The continuance of the permit for impounding water is contingent upon the application of control measures satisfactory to the State Board of Health. These control measures may include one or more of the following: Fluctuation of water level, removal of flotage and drift, removal of aquatic or other growth, application of larvicides, screening, or any other measures effective in the control of malaria.

After the water is impounded, representatives of the State Board of Health may make occasional inspections, and any condition found to be detrimental to public health, or likely to cause an increase of

malaria shall be remedied to the satisfaction of the State Board of Health.

SOUTH CAROLINA

Any person, corporation, or agency desiring to impound water for any purpose whatsoever must secure a permit from the State Board of Health. This regulation applies to all ponds and reservoirs except those for the sole purpose of watering stock.

All trees, brush, debris, and similar material within the reservoir which would pierce the water surface at minimum low water level or which would float or collect flotage on the surface of the water must be removed, burned, or otherwise satisfactorily disposed of prior to impounding the water.

The shore line of the reservoir from minimum low water level to a line 5 feet landward from the maximum high water level must be cleared and maintained clear of all brush and undergrowth. The brush, trees, and undergrowth in this zone must be cut off 6 inches or less above the normal ground surface.

All depressions which will be filled with water from the reservoir at times of maximum water level and which will retain water at lower stages of the reservoir must be connected with the reservoir so as to insure complete drainage or fluctuation of the water within the depression. If this requirement is not complied with, mosquito breeding in such pools must be controlled by adequate larviciding.

Whenever it is possible and advisable in the opinion of the State Board of Health, the water elevation of the reservoir should be fluctuated according to a schedule approved by the State Board of Health.

The validity of the permit for impounding water is contingent upon the following:

> During the mosquito-breeding season all flotage and debris that create conditions favorable for the production of mosquitoes must be kept regularly and frequently removed. Larvicides must also be applied to all mosquito-breeding areas of the reservoir whenever necessary to control adequately the production of *Anopheles* mosquitoes.
>
> After the water is impounded, representatives of the State Board of Health may make occasional inspections, and any conditions found to be detrimental to public health, or likely to cause an increase of malaria, shall be remedied to the satisfaction of the State Board of Health.

TENNESSEE

Any person, corporation, or governmental agency desiring to impound water with more than 1 acre of water surface, or to raise the level of an existing pool, must secure a permit from the State Department of Public Health.

In the designing and construction of a reservoir bottom drains or other means must be provided which will permit removal of the impounded water. Flashboards or other means must also be provided for controlling fluctuation of the water level at any season of the year.

In the area to be inundated by the impounded water all trees and other growth which would pierce the surface at minimum low water level must be cut off at least 1 foot below such water level to prevent the collection of drift and flotage.

The shore line from minimum low water level to a line 15 feet landward from the normal high water level must be cleared of all brush, trees, undergrowth, and any material which may cause the collection of drift or flotage.

Any area which will be inundated by impounded water at the time of maximum water level and in which water will be retained at lower stages of the reservoir must be connected with the main body of the impounded water so as to permit drainage or access by boat.

The reservoir must not be filled during the breeding season of the malaria-carrying mosquito unless authorized by the State Department of Public Health.

All brush, vegetation, and similar material must be removed annually in the autumn or winter months from the shore line where it might cause the collection of drift or flotage.

Waterlilies, water hyacinths, or other aquatic plants which grow above or penetrate the surface of the water must not be planted or transplanted into any reservoir.

The water level of the reservoir must be controlled in a manner satisfactory to the State Department of Public Health.

Larvicides, such as DDT, paris green, and oil, must be applied when such measures are required to control the malaria-carrying mosquito.

Where it is not possible to control adequately the breeding of malaria mosquitoes, or where such control is not practical or economical, the Health Commissioner may require that the person responsible for the reservoir effectively screen all houses within 1 mile of the impoundage, spray such houses with an insecticide when specified, or carry out such other malaria control measures as may be deemed necessary or appropriate for the control of malaria.

After the water is impounded, representatives of the State Department of Public Health may make occasional inspections, and any conditions found to be detrimental to public health, or likely to cause an increase of malaria, should be remedied to the satisfaction of the State Department of Public Health.

TEXAS

All persons, firms, corporations, and governmental agencies that impound any body of water for public use shall cooperate with the State and local departments of health in the control of disease-bearing mosquitoes on the impounded area.

VIRGINIA

Any person or corporation desiring to impound water must take the necessary measures to control the breeding of the malaria-carrying mosquito. Some of these measures are as follows:

All trees, brush, debris, and similar material within the reservoir which would float or collect flotage on the surface of the water must be removed, burned, or otherwise satisfactorily disposed of prior to impounding the water. Vegetation, brush, trees, stumps, etc., which will be permanently and completely submerged at time of low water need not be removed. All trees and underbrush which would pierce the surface of the water at any and all stages must be cut off sufficiently below such water levels so as to prevent the collection of drift or flotage.

The collection of drift and flotage in bights along the banks of the reservoir where there is little wave action must be prevented during the mosquito-breeding season.

Insofar as practicable, the water level in the reservoir should be fixed so as to reduce to a minimum shallow areas in which aquatic plants will grow.

The shore line of the reservoir from minimum low water level to a line at least 15 feet landward from the normal high water level must be cleared of all brush, trees, and other material which might cause the collection of drift or flotage.

All pools and seepage places created during construction of the dam or by impounding the water must be filled, connected with the reservoir, or stocked with top minnows *(Gambusia)*.

Where the above measures fail to control mosquito breeding, other control measures must be used, such as larvicides, drainage, or other control measures.

APPENDIX B

EXAMPLE OF HYDRAULIC ANALYSIS FOR PREDICTION OF THE FREQUENCY AND DURATION OF FLOODING IN A FLOOD CONTROL STORAGE RESERVOIR

In studying the establishment of the basic clearing line, it is necessary to know the expected stages of the reservoir during the mosquito-breeding season and their frequency and duration of occurrence. Prior to impoundage this information can be estimated from a statistical analysis of predicted hydrographs for the reservoir. Such hydrographs will usually be available from the hydraulics division as they are necessary in the design of the spillway and in the over-all planning and operation of the project. If such hydrographs are not available, they may be prepared from analysis of recorded stream flow data, anticipated discharge of controlled release, and the storage-volume curve for the reservoir. Examples of three such hydrographs (1913, 1928, and 1936) predicted for Sardis Reservoir on the Tallahatchie River in Mississippi, prior to its impoundage, are shown in figure 195. These hydrographs show the daily stages for the entire year and the maximum pool elevation during the significant mosquito-breeding season which would have occurred during the years shown had the reservoir been impounded at that time and operated in accordance with the assumed design plan. Such curves also show the length of time any given elevation would have been exceeded during the mosquito season for that particular year. From a statistical analysis of the maximum pool elevations occurring during the mosquito season for all the recorded years available, it is possible to predict their frequency of occurrence. An example of a method for computing the frequency of maximum reservoir stages which may be expected to occur during the mosquito-breeding season is given for Sardis Reservoir in the following paragraphs.

Using theoretical hydrographs (1901-37), which were prepared for Sardis Reservoir prior to its impoundage, the highest reservoir stage occurring between May 1 and October 15 was taken from the hydrograph for each year. These stages are shown in table 40. Figure 195 shows some typical hydrographs (1913, 1928, and 1936) from which the maximum stages were taken. This figure also shows estimated mean stages for various days of the year that will occur or be exceeded 50 percent of the time or once every other year on the average. These mean or median stages for various days were computed from the theoretical hydrographs (1901-37) referred to above.

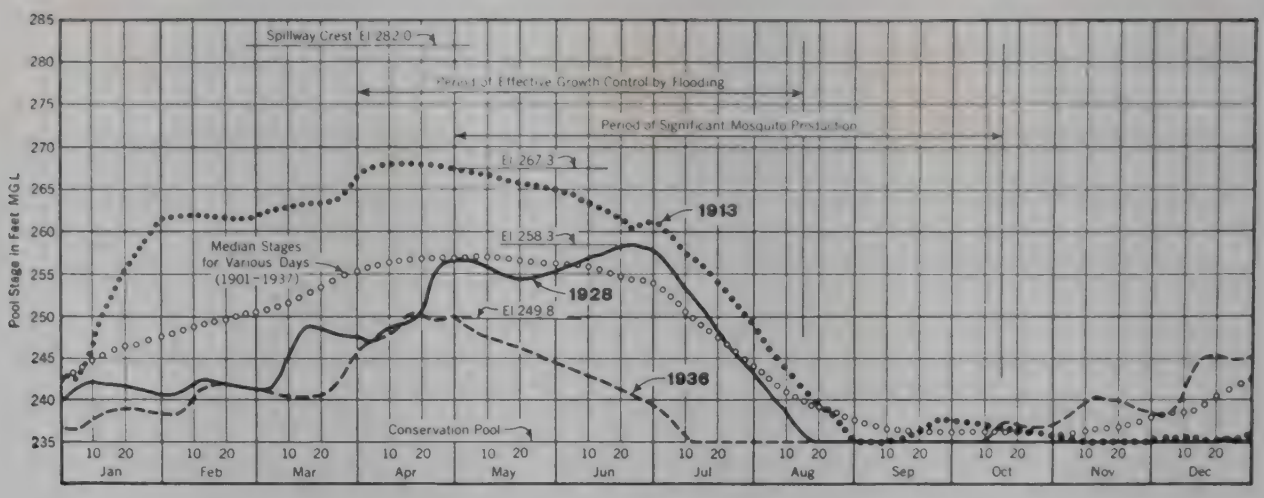

FIGURE 195.—Theoretical hydrographs for Sardis Reservoir prior to impoundage.

The data in table 40 can be analyzed to predict the maximum stage and frequency of flooding during the mosquito season in the following way:

1. Make an array of the data in table 40. (See table 41.)

2. Group the data. (Select an interval of 2 to 5 feet so as to obtain 10 to 15 points for plotting the probability curve. An interval of 4 feet was used in the example for Sardis Reservoir. Note method of grouping in table 41, e.g., range of group 248.0 includes all stages between 246.0 and 249.9. The number of occurrence within each group is shown in the parentheses.

TABLE 40.—*Maximum reservoir stages (May 1 to Oct. 15) taken from theoretical hydrographs for Sardis Reservoir, Tallahatchie River, Miss.*

Year	Stage	Year	Stage	Year	Stage
1901	251.1	1914	248.0	1926	249.6
1902	260.7	1915	257.0	1927	265.8
1903	258.3	1916	255.4	1928	258.3
1904	251.8	1917	265.0	1929	255.4
1905	265.9	1918	239.3	1930	255.7
1906	245.6	1919	257.8	1931	245.7
1907	263.2	1920	271.5	1932	278.9
1908	257.0	1921	263.2	1933	275.5
1909	262.0	1922	264.3	1934	244.2
1910	247.6	1923	270.5	1935	262.0
1911	258.1	1924	262.5	1936	249.8
1912	279.0	1925	239.5	1937	256.8
1913	267.3				

3. Arrange the groups and number of maximum stages occurring within each group as shown in columns (a) and (b), table 42.

4. Add the number of stages (column c).

5. Compute the number of stages equal to or less than the center of the group indicated (column d).

(Assume the number of stages within each group to be equally distributed, e.g., for Group 240, column d = ½ (column b) = 1; for Group 244, col. d = column c for Group 240 + ½ (column b for Group 244) = 3.5; etc.

TABLE 41.—*Array of maximum stages.*

Stage	Group and frequency	Stage	Group and frequency	Stage	Group and frequency
239.3	240 (2)	255.4	256 (7)	262.0	264 (9)
239.5		255.4		262.0	
		255.7		262.5	
244.2	244 (3)	256.8		263.2	
245.6		257.0		263.2	
245.7		257.0		264.3	
		257.8		265.0	
247.6				265.8	
248.0	248 (4)	258.1	260 (4)	265.9	
249.6		258.3			
249.8		258.3		267.3	268 (1)
		260.7			
251.1	252 (2)			270.5	272 (2)
251.8				271.5	
				275.5	276 (1)
				278.9	280 (2)
				279.0	

TABLE 42.—*Computation of frequency curve.*

Stage (group)	Number of stages	Cumulative sum of stages	Number of stages $\leq$ center of each group	Percent $\leq$ given stage	Percent $\geq$ given stage	Frequency of occurrences in years
(a)	(b)	(c)	(d)	(e)	(f)	(g)
240.....	2	2	1	2.7	97.3	1.03
244.....	3	5	3.5	9.5	91.5	1.09
248.....	4	9	7	18.9	81.1	1.23
252.....	2	11	10	27.0	73.0	1.37
256.....	7	18	14.5	39.1	60.9	1.64
260.....	4	22	20	54.0	46.0	2.17
264.....	9	31	26.5	71.5	28.5	3.50
268.....	1	32	31.5	85.2	14.8	6.75
272.....	2	34	33.0	89.2	10.8	9.25
276.....	1	35	34.5	93.2	6.8	14.7
280.....	2	37	36.0	97.3	2.7	37.0

6. Compute the percent of maximum stages $\leq$ the stage indicated as shown in column e (column d $\div$ *total* number of occurrences) $\times$ 100.

7. Compute the percent of maximum stages $\geq$ the stage indicated as shown in column f (100 — column e).

8. Compute the probable frequency of occurrence of the stage indicated as shown in column g (100 $\div$ column f). For example, the pool will probably reach an elevation of 260.0 once in every 2.17 years between May 1 and October 15.

The data in table 42 may be used to plot a frequency curve in percent or in years (fig. 196). In this particular example, the data shown in columns (a) and (e) were plotted on arithmetic probability paper to obtain the frequency curve shown in figure 196. The probable frequency of occurrence of any maximum stage during the mosquito-breeding season can be obtained from this curve. (See table 43.)

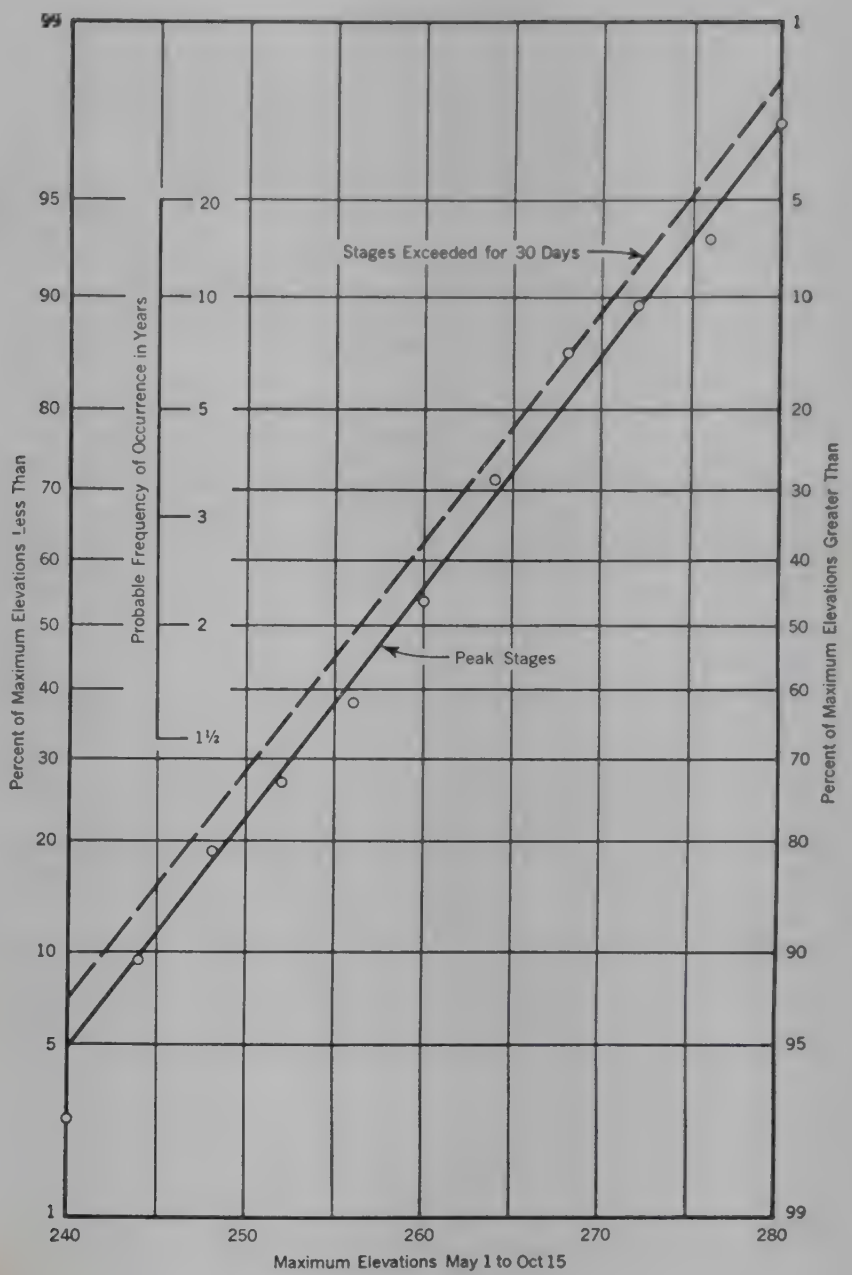

FIGURE 196.—Probable maximum stages during significant *A. quadrimaculatus* breeding season (May 1 to Oct. 15) and their frequency of occurrence. Sardis Reservoir, Mississippi.

TABLE 43.—*Probable maximum stages (May 1–Oct. 15) for Sardis Reservoir and their frequency of occurrence.*

Maximum stage	Frequency of occurrence (years)	Maximum stage	Frequency of occurrence (years)
240	1.03	253.6	1½
250	1.3	258.3	2
260	2.2	263.2	3
270	6.8	267.6	5
280	37	272.5	10

In the preceding example for simplicity, the highest stage occurring between May 1 and October 15 for each year was used in the statistical study of probability of flooding. A similar procedure may be used to predict the frequency of flooding above any given elevation for any assumed period of time such as is shown for a 30-day period in figure 196. Similar data could be obtained on flooding during the plant growing season. These charts should be useful in planning shore-line maintenance, application of larvicides, and supplementary measures such as mosquito-proofing and house-spraying.

APPENDIX C

CHEMICALS EMPLOYED IN MALARIA CONTROL[11]

LARVICIDES AND ADULTICIDES

Black oil

Specifications—Black oil should be a pure petroleum product free from fatty oils, fatty acids, resins, soaps or other nonhydrocarbons. Sediment and sludge, insoluble in paraffin naphtha, should not exceed 12 percent when determined by the methods of the American Association of State Highway Officials. The product should be a distilled or fractionated oil, and should contain no oil-well water or residue therefrom. The product should be free of or contain no more than traces of naphthenic acids, naphthene derivatives, mercaptans, soluble sulfide, and volatile surfur derivatives. The oil should flow freely from the tank car at temperatures above 32° F.

DDT

Chemical Formula — [2,2-bis-(p-chlorophenyl)-1,1,1-trichloroethane]. The chemically pure product consists of needle-shaped, white crystals which melt at 108° C. and can be obtained by recrystallizing the technical material from ethyl alcohol. DDT is prepared by condensing chloral or chloral hydrate with monochlorobenzene in the presence of concentrated sulfuric acid.

Specifications—DDT should conform to Joint Army-Navy Specifications JAN D-56A for dichlorodiphenyl-trichloroethane (DDT) Grade B, Technical and should be a fine-to-medium granular powder with a white to cream color, with a minimum setting point of 90° C. It should contain from 48 to 51 percent organic chlorine by weight and the ash content should not exceed 0.5 percent by weight. The water insoluble, steam volatile material should not exceed 0.1 ml. per 20 gm. The chloral hydrate should not exceed 0.025 percent by weight. The pH by distillation should range from 4.5 to 8.0 and by extraction from 5.0 to 8.0. The water soluble material should not exceed 0.25 percent and the cyclohexanone insoluble material by weight should be 0.2 percent.

Shipment should be made in tight metal or fiber containers complying with ICC specifications, each containing 100 pounds of DDT.

[11] Materials and equipment identified by trade names in this publication are so described solely for the purpose of avoiding the detailed technical descriptions that would otherwise be required. Such identification does not constitute endorsement of any commercial product by the U. S. Public Health Service or the Tennessee Valley Authority. Only partial lists of vendors are given and any products equivalent to those named would be equally usable.

Sources: Geigy Company, Inc., New York, N. Y.
Monsanto Chemical Co., St. Louis, Mo.
Merck and Co., Rahway, N. J.
General Chemical Co., Marcus Hook, Pa.
Pennsylvania Salt Manufacturing Co., Philadelphia, Pa.
Michigan Chemical Co., St. Louis, Mich.
E. I. du Pont de Nemours & Co., Wilmington, Del.

Kerosene

Specifications.—Kerosene should conform to Federal Specification V-K-211A, and should have a specific gravity between 0.824 and 0.795 at 60° F. At least 25 percent, 50 percent, 75 percent, and approximately 100 percent by volume of the kerosene should be distilled off at 210°, 220°, 230°, and 300° C., respectively. The product should be a distilled or fractionated oil. The product should contain no oil-well waters or residue therefrom. The product should be free of or contain no more than traces of naphthenic acids, naphthene derivatives, mercaptans, soluble sulfide and volatile sulfur derivatives.

Paris green

Chemical formula.—Copper aceto-arsenite $Cu(CH_3COO)_2 \cdot 3Cu(AsO_2)_2$, a complex of copper meta-arsenite and copper acetate. Average CuO content 30.5 percent, average As_2O_3 content 56.8 percent, of which 1.2 percent is water soluble. Paris green is prepared by boiling basic copper acetate with arsenious trioxide and acetic acid.

Specifications.—Paris green should have a fineness so that at least 95 percent will pass a 200-mesh screen, at least 85 percent will pass a 325-mesh screen, and at least 75 percent will consist of particles 20 microns or greater in diameter (all percentages are by weight). It should contain approximately 55 percent arsenious oxide with not more than 3½ percent being soluble in water. It should be lethal to anopheline larvae when applied in natural breeding areas and should weigh not less than 60 pounds per cubic foot. Shipment should be made in tight metal or fibre containers complying with ICC specifications, each containing 100 pounds of paris green. Containers should not be larger than 15 inches in diameter by 18 inches high.

Sources: General Chemical Co., New York, N. Y.
Chipman Chemical Co., Cleveland, Ohio.
Sherman-Williams Co., Bound Brook, N. J.
Dow Chemical Co., Midland, Mich.
Ansbacher-Siegle Corp., 304 N. 7th St., New York, N. Y.

Pyrethrum extract

Specifications.—The pyrethrum content shall be not less than 2½ percent pyrethrins or 2.0 grams of pyrethrins for 100 cc. It shall be soluble in deobase oil. The concentrate shall be deodorized, clarified, and dewaxed.

Sources: McLaughlin Gromley King Co., Minneapolis, Minn.
Dodge & Olcott Co., 180 Varick St., N. Y.

Benzene hexachlorocyclohexane (666) (Gammexane)

Source: E. I. Dupont de Nemours & Co., Wilmington, Del.

SOLVENTS

Kerosene

(See *Larvicides and Adulticides*)

Xylene

Specifications.—The technical material shall be a water-white aromatic liquid boiling from 260°-350° F. with a flash point of 80°–90° F. The specific gravity shall range from 0.84 to 0.87 at 20° C. The material shall have a pleasant aromatic odor and be free from sulfur compounds. At 20° C., the material shall dissolve and maintain a stable solution of which at least 35 percent of the total weight is technical DDT.

Sources: Most any of the large oil companies or chemical supply houses should be able to supply this material.

Methylated naphthalenes

Specifications.—The technical material shall be a liquid distilling between 500°–700° F. It should have a minimum flash point of 175° F. and should be composed of at least 70 percent tri- and tetramethyl naphthalenes. The material should not contain appreciable amounts of benzene, xylene, toluene, paraffin hydrocarbons or sulfur compounds. At 20° C., this material should dissolve and maintain a stable solution of which at least 30 percent of the total weight is technical DDT. The solvent should be free from methylcholanthrene, dibenzanthracene, benzopyrene, and other known carcinogenic (cancer producing) hydrocarbons.

Sources: Most any of the large oil companies or chemical supply houses should be able to supply this material.

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EMULSIFIERS

Residual spray emulsifiers

Specifications.—This material, mixed in the proportion of: emulsifier—2 percent, DDT—30 percent, and xylene—68 percent, shall form a stable emulsion when 5 parts water by volume are added. It should be nontoxic when used in spraying operations, free from objectionable odor, and nonstaining to furniture and fabrics.

Sources: American Cyanamid & Chemical Corporation, 30 Rockefeller Plaza, N. Y.:
- Vatsol Series.
- Aerosol Series.

Colgate-Palmolive-Peet Co., 105 Hudson Street, Jersey City, N. J.:
- Arctic Syntex Series.
- Vel.

Monsanto Chemical Co., 1700 South Second St., St. Louis, Mo.:
- Santomerse Series.
- Aresket.

Atlas Powder, Wilmington, Del.:
- Span Series.
- Arlacel Series.
- Atlas G Series.
- Tween Series.

General Dyestuff Corporation, 435 Hudson Street, N. Y.:
- Igepon Series.
- Igepal CA.
- Colloresine DKN.
- Nekal Series.
- Emulphor Series.

Dewey & Almy Chemical Co., Cambridge, Mass.:
- Daxad Series.

E. I. du Pont de Nemours & Co., Inc., Wilmington, Del.:
- M P—189 Series.
- Duponol Series.

Emulsol Corporation, 59 E. Madison St., Chicago, Ill.
- Solvitt A.
- Emcol Series.

Proctor & Gamble Co., Department TR., Gwynne Building, Cincinnati, Ohio:
Orvus WA.
Gardinol Series.
Modinal Series.

Rohm & Haas Co., 222 West Washington Street, Philadelphia, Pa.:
Triton Series.

Larvicide emulsifiers

Specifications.—This material, mixed in the proportion of: emulsifier—0.5—2.0 percent, DDT—0.5—2.0 percent, and fuel oil—99–96 percent, shall form a "loose" or fast-breaking emulsion when applied to water surfaces as an atomized spray.

Sources: (See *Residual spray emulsifiers*)

LARVICIDAL DUST DILUENT

Soapstone, powdered

Specifications.—The soapstone should be dry, free from lumps or foreign matter, and ground fine so that 98 percent will pass a 200-mesh screen. The material should be shipped in paper bags containing 50 pounds each.

Sources: The Cohutta Talc Co., Dalton, Ga.
Lookout Paint Mfg. Co., Chattanooga, Tenn.
Blue Ridge Talc Co., Henry, Va.

HERBICIDES AND ARBORICIDES

Acid sodium arsenite.
Ammonium sulphamate.
Calcium arsenate.
Diesel oils.
Kerosene.
Sodium arsenite.
Sodium chlorate.

Sources: Most large oil companies or chemical supply houses can supply these materials.

2,4–d (2,4– dichlorophenoxyacetic acid).
Salts of 2,4–d.
Esters of 2,4–d.

Sources: American Chemical Paint Co., Ambler, Pa.
Associated Chemists, Inc., North Collins, N. Y.
Chipman Chemical Co., Portland, Oreg.
Dow Chemical Co., Midland, Mich.
E. I. du Pont de Nemours Co., Wilmington, Del.
Monsanto Chemical Co., St. Louis, Mo.
The Sherwin-Williams Co., Cleveland, Ohio.
United States Rubber Co., New York, N. Y.

APPENDIX D

EQUIPMENT, TOOLS, AND SUPPLIES[12]

Ax, 4-lb., double-bitted, thin blade, Western pattern. "Kelly's Paul Bunyan," with 36-inch grade AW hickory handle—American Fork & Hoe Co., or equal.

Bush hook, 3-pound, double-edged, 3¼ by 11-inch blade of one-piece tool steel, "Kelly's blade No. 32," with grade AW hickory handle—American Fork & Hoe Co., or equal.

Can, 5-gallon, safety, nonexplosive type.

Cup drinking, flat, 20-pound, white paper, 8-ounce capacity.

Dust mixer, complete with horizontal, motor driven, mechanical mixer, elevator, aspirator, and bagger. Dust mixer designed to mix batches of 10 to 20 cubic feet of dust—Robinson Manufacturing Co., Muncie, Pa., or equal.

Duster, hand. Duster should be of the crank type and of such design that it can be carried in front of operator and should be furnished with a web strap for carrying. The dust container should be of the metal drum type and have a capacity of approximately 650 cubic inches. The agitator should be of the metal disk type attached to crankshaft in the middle of the hopper. The dust aperture should be adjustable and have a maximum opening of ¼ by ⅜ inch and located in the bottom of the hopper immediately under the metal agitator. Fan shall be of the metal blower type mounted on the outside of the dust hopper and should be enclosed. The gear should be packed with grease and sealed in gear case and should have a gear ratio of 62 revolutions of fan to 1 for the crank. The nozzle arm should rotate for dusting in front or back of operator. The nozzle should be detachable and of the metal fan type. Net weight of the duster should not exceed 15 pounds—Root Manufacturing Co., Cleveland, Ohio; John Bean Manufacturing Co., Lansing, Mich.; or equal (fig. 197).

Duster, power. A power orchard duster should have a hopper capacity of about 3 cubic feet with a variable feed opening and dust agitating device. The unit should be equipped with a 20-inch diameter fan that will produce a wind velocity of 175 miles per hour at the fan case outlet, and a 4-inch, 6-foot wire-wound, flexible, dust

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FIGURE 197.—Root hand duster.

hose. The dusting mechanism should be directly connected to a 5 horsepower Briggs & Stratton (or equal) four-cycle, air-cooled gasoline engine. The crank starter should be equipped with a roller grip. The engine should be provided with a compression release to facilitate cranking. The complete unit should be mounted on a substantial base. Net weight of the unit should not exceed 300 pounds.—Root Manufacturing Co., Cleveland, Ohio; John Bean Mfg. Co., Lansing, Mich.; F. E. Myers & Bros., Batavia, N. Y.; or equal (fig. 198).

Fire extinguishers, Pyrene 1-quart, or Phomene 2½-gallon capacity, or equal.

Fire-fighting pump, 5-gal., "Indian" No. 90—G—D. B. Smith Co., or equal.

Fire rake, mower-tooth section, 5-foot ash handle, No. LW-12—Council Tool Co., Wananish, N. C., or equal.

Goggles, airtight, rubber mask type with heavy, clear lens—G-520 Wilson Products, Inc.; Mine Safety Appliance Co.; or equal.

Hacksaw, 12-inch frame, adjustable from 8 to 12 inches, pistol-grip, all steel handle.

Hammer, crosscut-saw setting. Head of hardened steel, 4 inches long, arc-shaped, with hickory handle, 7¾ inches long. Weight 16 ounces—Atkins No. 4, Disston's setting and swaging hammer or equal.

Handle, crosscut-saw, reversible, 131/2 inches long by 13/8-inch diameter, with extra heavy face-weight, washer bolt, and wing nut. All parts of malleable iron—Simond's No. 111B, or equal.

Handles, ax, double-bitted, 36-inch straight, oval, grade AW hickory.

Handles, bush hook, double-edged 36-inch straight, oval, grade AW hickory.

Handles, timber carrier, 21/2-inch by 4-feet, select hickory or maple.

Hoist, chain, screw geared, 1-ton rated capacity with 8-foot lift, weight approximately 60 pounds—Yale or equal.

Life preservers, style No. 10, size 3 and 4, large olive drab, vest type—American Pad & Textile Co., Greenfield, Ohio, or equal.

Life preservers, solid block cork vest type, adult size 4 by 12 x 26 inches conforming to latest Department of Commerce regulations, U. S. inspected and stamped.

Marine motor, inboard, gasoline operated to develop 24 horsepower at 1,200 revolutions per minute. The engine should be 4-cylinder, 4-cycle, heavy duty, water-cooled type, equipped with integral reverse gear of at least 90 percent reverse gear ratio. The cylinders should be cast in pairs with detachable type head. Crankshaft should be drop-forged and not less than 11/2 inches in diameter. The engine should be provided with water-cooled exhaust manifold, fuel pump, gasoline strainer, Bosch magnetic ignition system with impulse coupling, and bronze plunger or rotary type water pump.

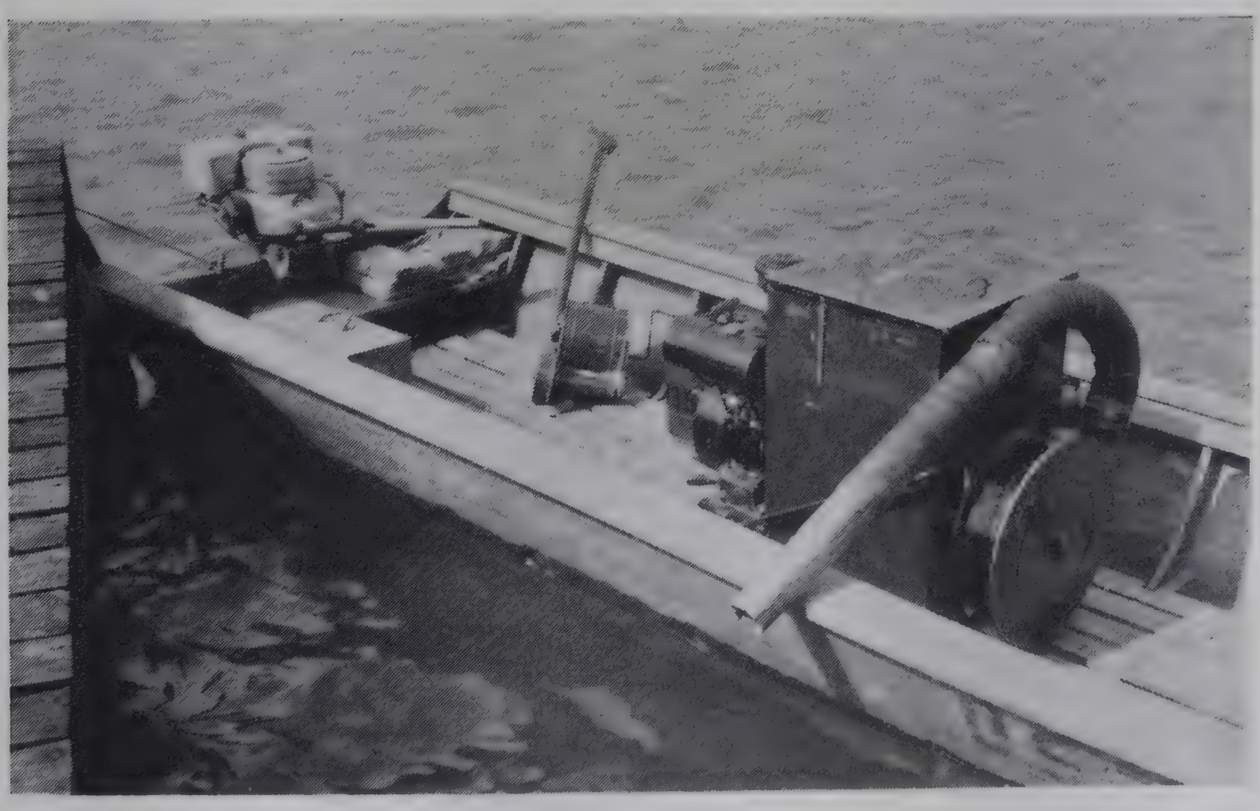


FIGURE 198.—Power dusting unit mounted in outboard motorboat.

Parts should be interchangeable between any other of like make and model—Red Wing Thoroughbred, Arrowhead, or equal.

Marine motor, outboard (for larvicidal work and slow travel). The motor should be a 2-cylinder, 2-cycle, gasoline motor that will develop about 10 horsepower at 4,000 revolutions per minute and weigh less than 65 pounds. The motor and propeller should pivot 360° for steering. The propeller should have three blades, and be of brass and of a size recommended by the manufacturer for heavy duty. The pump for the water-cooling system should be of the vacuum type —Model KA Johnson Motors, Waukegan, Ill., or equal.

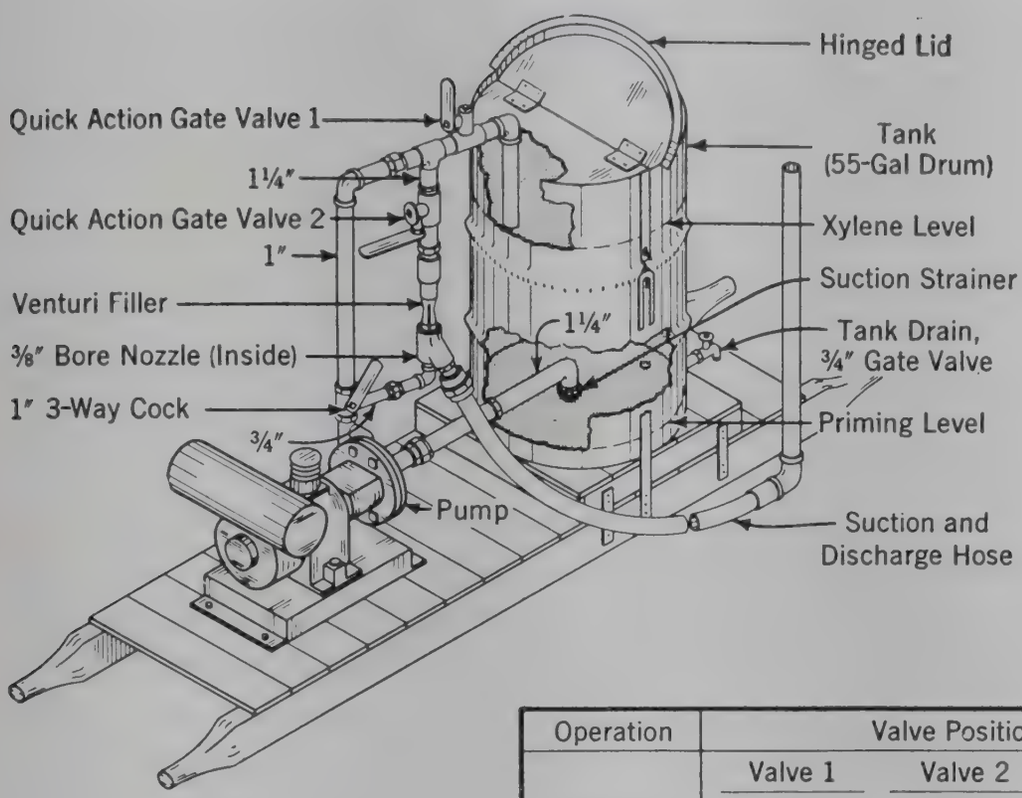
Marine motor, outboard (for inspection work and fast travel). The motor should be a 2-cylinder, 2-cycle, gasoline motor, weighing less than 115 pounds. It should have a twist-grip speed control. The motor and propeller should pivot 180° for steering. The motor should develop 22 hp. at 4000 r.p.m. The propeller should have 3 blades, and be of brass and of a size recommended by the manufacturer for heavy duty work. The water-cooling system may have a vacuum or pressure-vacuum type pump—Johnson, Model P. O.; Evinrude, Speedtwin; or equal.

Mixer, power. DDT concentrate may be quickly prepared with a portable power mixer as shown in figures 118 and 199. This mixer consists of a gasoline engine-driven centrifugal pump, a mixing tank, valves, piping and fittings, and a wood base. The piping is so arranged that by proper manipulation of the valves the unit will draw solvent from a drum into the mixing tank, recirculate it to dissolve the DDT in the solvent, and discharge the final concentrate into storage containers.

The centrifugal pump of the power mixer should preferably be of the closed impeller type with a ground joint shaft seal and have a capacity of about 45 gallons per minute with a head of 80 feet at a speed of 2,400 revolutions per minute. A suitable pump unit complete with direct-connected 1½ horsepower single-cylinder gasoline engine of the 4-cycle, air-cooled type, may be obtained from the Berkeley Pump Co., Atlanta, Ga.

The quick action gate valves, 3-way cock, and venturi filler are commercially available. The venturi filler may readily be assembled from the following parts available from Bean Mfg. Co., Lansing, Mich.: one Inlet Body No. 12602, one Venturi Body No. 12603, and one Injector Nozzle 13651.

An alternate power mixer is shown in figure 200. This mixer is equipped with an open impeller, self-priming type, centrifugal pump connected directly with a gasoline engine. Four-gate valves are required to control the complete mixing operation. With careful



Operation	Valve Positions		
	Valve 1	Valve 2	3-Way Cock
Suction	Open	Open	L
Recirculation	Open	Closed	R
Discharge	Closed	Open	R

FIGURE 199.—Isometric cutaway sketch of venturi power mixer.

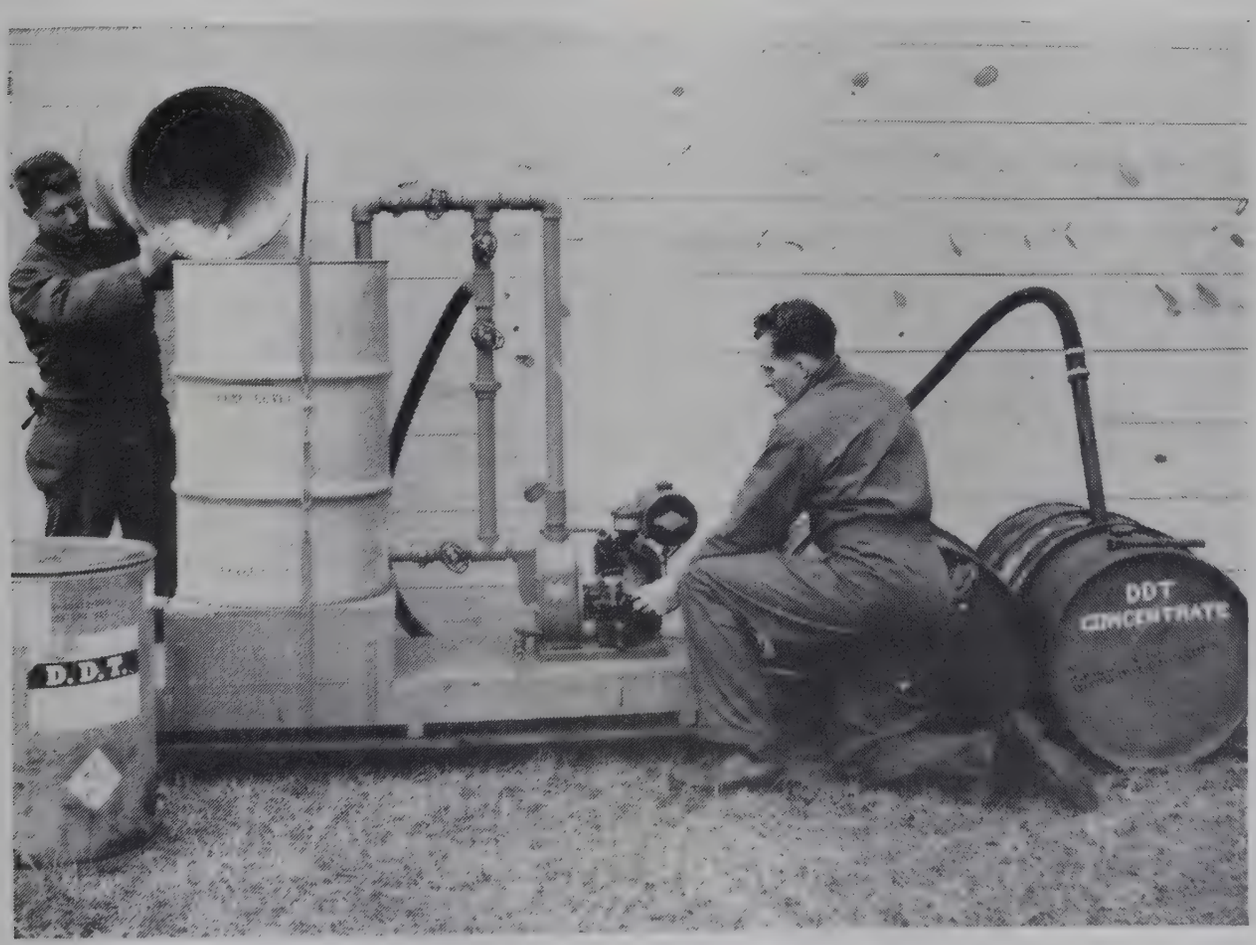


FIGURE 200.—Power mixer in operation.

manipulation of the valves, solvent may be pumped into the mixing tank, recirculated for mixing DDT, and the resultant concentrate pumped out of the unit without the loss of prime in the pump. If this type mixer is chosen, care should be taken to select a pump containing a shaft seal that is not affected by the solvent. The Deming Co., Salem, Ohio, manufactures a pump with a direct-connected gasoline engine which is satisfactory.

Mowing machine, horse drawn, built for extremely heavy duty, high speed, capable of running in semiraised position, complete with 4½-foot blade, cutter bar, pitman rod, roller bearings on one-piece axle, ball bearings on rear end of pitman shaft, double trees, and neck yoke. The machine should be equipped with heavy duty steel rock guards. The pitman rod to be capable of release from knife head without use of a wrench and so designed and constructed as to prevent straps from getting too tight through use of a coil spring on plunger. All gears should be enclosed. Axle bearings, counter shaft, and pitman shaft bearing and main operating parts should be oiled directly from oil reservoir in gear case. There should not be more than 2 gear steps in delivering power from drive wheels to the sickle. The mower should have high foot and hand lifts permitting maximum lift of cutter bar at inner end—John Deere Plow Co.'s Big 4, or equal.

Mowing machine, tractor. (Ford-Ferguson, International Harvester Co. Model A tractor, or equal) with heavy-duty mower attachment (Ferguson-Sherman, or equal). The mower should be side-mounted, hydraulically or pneumatically controlled and capable of being lowered 45° below the horizontal. The mower blade should be 6 feet long and equipped with rock guards and extra heavy duty sections. The mower mounting-bracket should include a breakaway to release the bar when it encounters a hidden obstruction.

Nozzle, atomizing, agricultural type: ¼ LN2, for hand larviciding.
¼ LN12, for airplane spraying.
Spraying System Co., Chicago, Ill.

Nozzles, residual-spraying, 50° nozzle:
Discharge, at 40 p. s. i. equals 0.2 g. p. m.—N¼T5002.
Discharge, at 40 p. s. i. equals 0.15 g. p. m.—N¼T50015.
Spraying System Co., Chicago, Ill.

Pitchfork, 4-tine, 5-foot handle.

Pump, gasoline, pedestal 1-gallon stroke, equipped with dial counter and meter, 1-inch brass, foot valve, and 8-foot x ¾-inch hose with nozzle. Pump designed for outdoor service and equipped with lock.

Pump, deep-well, complete with stand and base bolts. All brass barrel fitted with bronze, ball valves and four leather, all brass plungers. Barrel 2¾-inch diameter by 18-inch stroke—F. E. Myers & Bros. 95½, or equal.

Pump, water-oil. Gasoline powered, rotary pump for boat oiler. The complete pumping unit should consist of a high pressure, rotary pump with 1¼-inch suction and discharge, and with a capacity of 30 g. p. m. at a discharge pressure of 50 pounds per square inch. The pump should be a Viking Model E K M, or equal. The pump should be connected to the motor by a friction clutch or to a 5-horsepower motor unit. The motor should be a single-cylinder, 4-cycle, air-cooled gasoline engine with magnetic ignition; a compression release should be provided on the engine to facilitate cranking; the crank starter should be provided with a roller grip; the net weight of the unit should not be more than approximately 225 pounds—Briggs & Stratton, Wisconsin, or equal (fig. 201).

Rake, 9-foot, 30-tooth, self-dumping with mountain wheel, roller bearings, ½-inch teeth, double trees, neck yoke, and tongue—McCormick Deering, or equal.

Respirator, dust and mist, type AC, mechanical filter type—Mine Safety Appliances Co., Approval No. 2101, or equal.

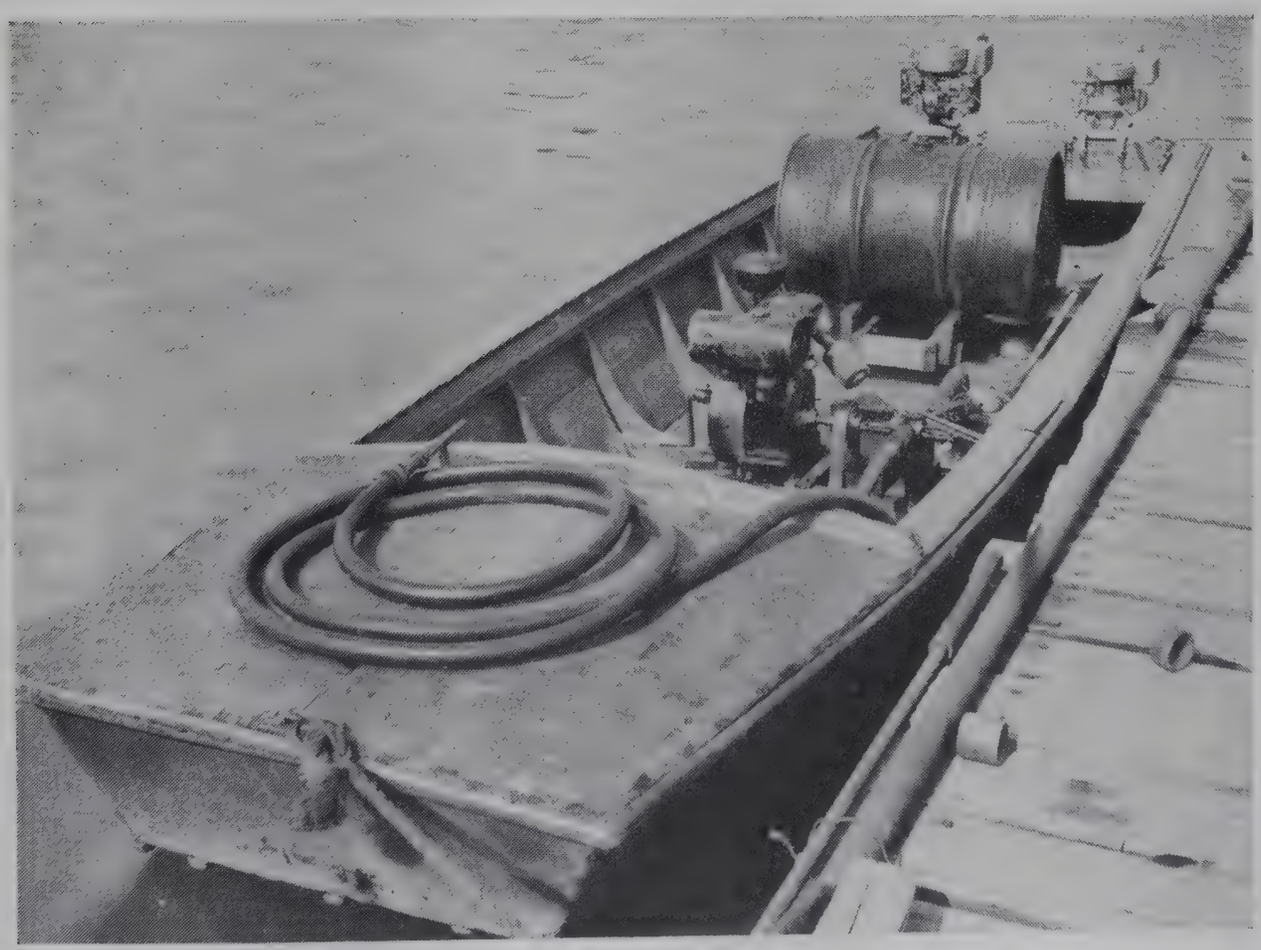
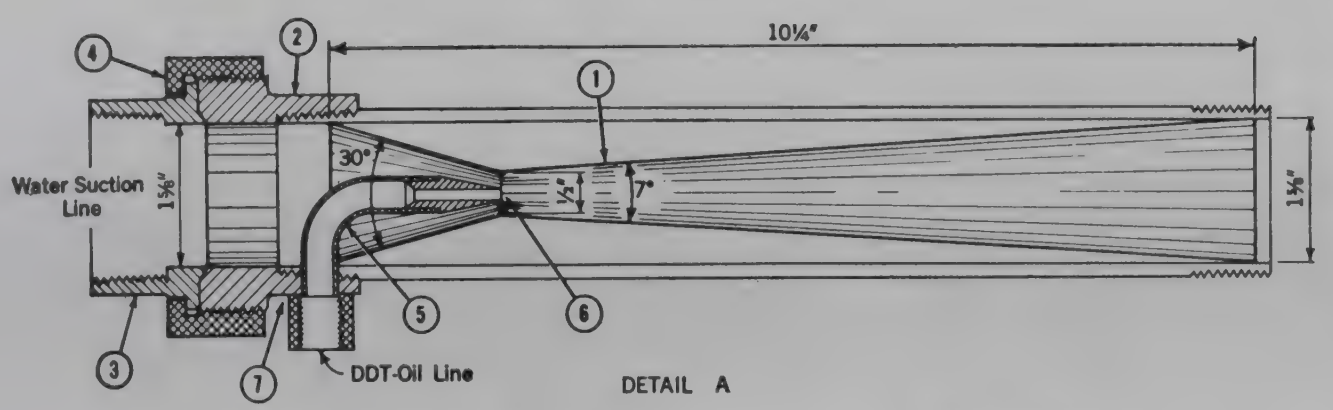
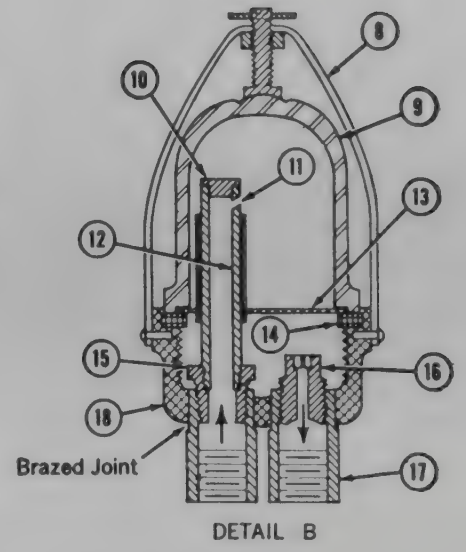
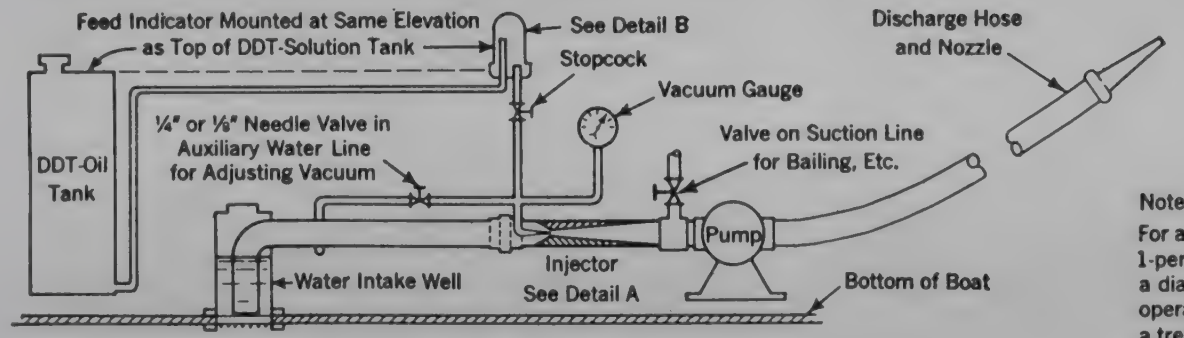


FIGURE 201.—Water-oil pumping unit mounted in an outboard-motorboat.






Feed Indicator Mounted at Same Elevation as Top of DDT-Solution Tank
See Detail B
Stopcock
Vacuum Gauge
Discharge Hose and Nozzle
¼" or ⅛" Needle Valve in Auxiliary Water Line for Adjusting Vacuum
Valve on Suction Line for Bailing, Etc.
DDT-Oil Tank
Pump
Water Intake Well
Injector See Detail A
Bottom of Boat

SCHEMATIC DIAGRAM
Showing Desirable position of Feed Indicator and Injector in Relation to Existing Features

Note: DDT-Oil Solution Metering Orifice Data
For a dosage of 0.05 pounds of DDT per acre using a 1-percent solution of DDT in oil the orifice must have a diameter of 0.036 inches (wire gauge No. 64) and operated at a vacuum of 5 inches of mercury, assuming a treatment rate of 1 acre per 11 minutes, or an injection rate of 0.0606 gpm.

LEGEND

(1) Sheet Metal Venturi
(2) Male Portion of 1½" Ground Joint Pipe Union
(3) Companion Part of Pipe Union
(4) Coupling Nut for Pipe Union
(5) ⅛" Oil-Solution Injector Assembly
(6) Outlet End of Injector Assembly—⅛" Hole
(7) One-Half of ¼" Wrought Steel Pipe Coupling
(8) Bowl Clamp Assembly
(9) Glass Sediment Bowl (Automobile Fuel Pump) Ford FP-102XG or Universal FP-102G
(10) Brass Plug Sweated into End of ⅛" Pipe Nipple
(11) 3/32" Hole Drilled (at Angle) Inside of ⅛" Brass Pipe Nipple to Form Visible Stream When Solution is Being Fed into System
(12) 2¼" Length of ⅛" Brass Pipe Threaded One End
(13) 60-Mesh Brass Wire Strainer
(14) Standard Cork Gasket for Sediment Bowl (Automobile Fuel Pump)
(15) Standard ¼" to ⅛" Pipe Bushing
(16) ¼" Brass Pipe Plug Altered to Serve as a Metering Orifice (Metering Orifice Drilled to Size—See Note)
(17) ¼" Steel Pipe Coupling Milled as Shown
(18) 1½" Standard Malleable Iron Pipe Cap, Milled as Shown, to Serve as Body for Assembly

FIGURE 202.—DDT-oil solution injector for use with a water-oil boat larviciding unit.

Respirator, chemical cartridge, complete with twin cartridge (GMA)—EM9328 Mine Safety Appliances Co., or equal.

Salt tablets, 7 grains sodium chloride, 3 grains dextrose.

Saw, 5-foot-6-inch crescent, 4 cutting teeth to one raker, 4⅝-inch width at center, 3⅜-inch width at ends, 14-gage thickness at tooth edge, 17-gage thickness at back at center, 16-gage thickness at back at ends, weight 4½ pounds—Disston No. 494, Simond's No. 325, or equal.

Saw set, crosscut—Simond's No. 342, or equal.

Saw, timber, portable, chain type, powered with a 2-cycle, air-cooled 5-horsepower gasoline power unit mounted directly on saw, with cutter bar equipped with a 36-inch special forest service cutting chain. The saw should be equipped with a suitable guard. Weight of complete unit should not exceed approximately 125 pounds—Mall Tool Co., Chicago, Ill., Mercury-Disston, or equal.

Screen wire. The following condensed specifications for iron or steel galvanized (zinc coated) screen wire cloth can be used for the purchase of material for mosquito-proofing against *A. quadrimaculatus,* or mosquitoes of similar size:

> The wire cloth should be made of iron or steel wire of commercial quality equal to low-carbon, open-hearth or Bessemer steel. Zinc coating should be by the electrolytic method after weaving, and the coating metal should be of zinc of at least 98 percent purity.
>
> The wire cloth should be free of any defects which might affect its serviceability or appearance and shall be properly salvaged on each edge. Well-made splices not over ¾ inch long and showing no tails will be permitted at any point of individual wires, provided that the number of splices does not exceed 30 in any roll or 2 in any 1 square foot.
>
> The mesh should be 16 per inch and shall be determined by counting the wires at any interval of 1 foot and dividing by 12. The warp and filler wires should have an average diameter of 0.011 inch, prior to zinc coating. This mean diameter can be determined by taking the combined average of the measured diameters of not less than 10 warp and 10 filler wires. Permissible variations are ¼ mesh per inch for the warp and ½ mesh per inch for the filler wires; for the wire diameter, 0.0005 inch.
>
> The individual wires should have an average tensile strength, as determined by testing equal numbers of warp and shoot wires, of at least 125,000 pounds per square inch, and all wire should have a tensile strength of at least 100,000 pounds per square inch.

FIGURE 203.—Knapsack spray can with agricultural mist-type nozzle for DDT-oil solutions.

The wire cloth should be in rolls of about 100 feet. At least 85 percent of the rolls should be in one continuous length and the remaining rolls in not more than two lengths each.

The widths of wire cloth should be as specified with allowable variation of 1/8 inch in width of the cloth measured from outside wire to outside wire.

Shovel, No. 2, round point, 4-foot 6-inch handle.

Shovel, No. 2, square point, 4-foot 6-inch handle.

Spray knapsack, 4-gallon capacity, with pump. The tank should be galvanized and formed to fit the operator's back comfortably, fitted with hose, lever shut-off cock, brass pipe extension and spray nozzle and shoulder carrying straps—Myers No. 133OA or D. B. Smith Co.'s E-Z, or equal. (For application of larvicidal or herbicidal oil.) (See fig. 203.)

Sprayers, "pump-up" type. Brown's Open Head No. 4, E. C. Brown, Rochester, N. Y., or Hudson's Industrial, H. D. Hudson Manufacturing Co., Chicago, Ill.

Sprayer, power. Orchard type, Bean No. 3, John Bean Manufacturing Co., Lansing, Mich.

Sprayer, skid type. Hardie No. 99X0105, Hardie Manufacturing Co., Hudson, Mich.

The power sprayer shown in figures 120 and 204 has proved satisfactory for rapid treatment of large buildings and dwellings

in urban areas. This unit, a small orchard-type power sprayer with minor alterations, consists of the following: a duplex plunger pump driven by a 1½ horsepower gasoline engine, a 50-gal. wood tank with agitator paddles, a surge chamber for minimizing pressure fluctuation, a pressure gauge, a pressure regulator, a coarse screen strainer on the suction pipe, and hose cut-off valves. The pump has a capacity of about 3½ g.p.m., at pressures up to 300 p.s.i. The sprayer should be equipped with a 70- or 80-mesh screen discharge strainer, two 100-foot lengths of ⅜-inch I.D., 2- or 3-ply, solvent resistant hose, and two spray guns with quick action shut-off valves, wands, and nozzles. The pressure regulator should be adjustable to provide pressures from 40 to 60 p.s.i.

The sprayer unit may be mounted on the bed of a ½-ton truck in such a manner that adequate space is left for cover cloths and other accessory equipment. If reels are not available, satisfactory hose racks (fig. 120) may be constructed of 1½-inch by ¼-inch scrap iron, covered with 1¼-inch I.D. rubber hose, and mounted on each side of the truck bed. For convenience in filling auxiliary hand sprayers and to facilitate flushing of the tank, a tank drain should be extended through the side of the truck bed.

To keep the power sprayer in good condition the following simple maintenance procedures are essential:

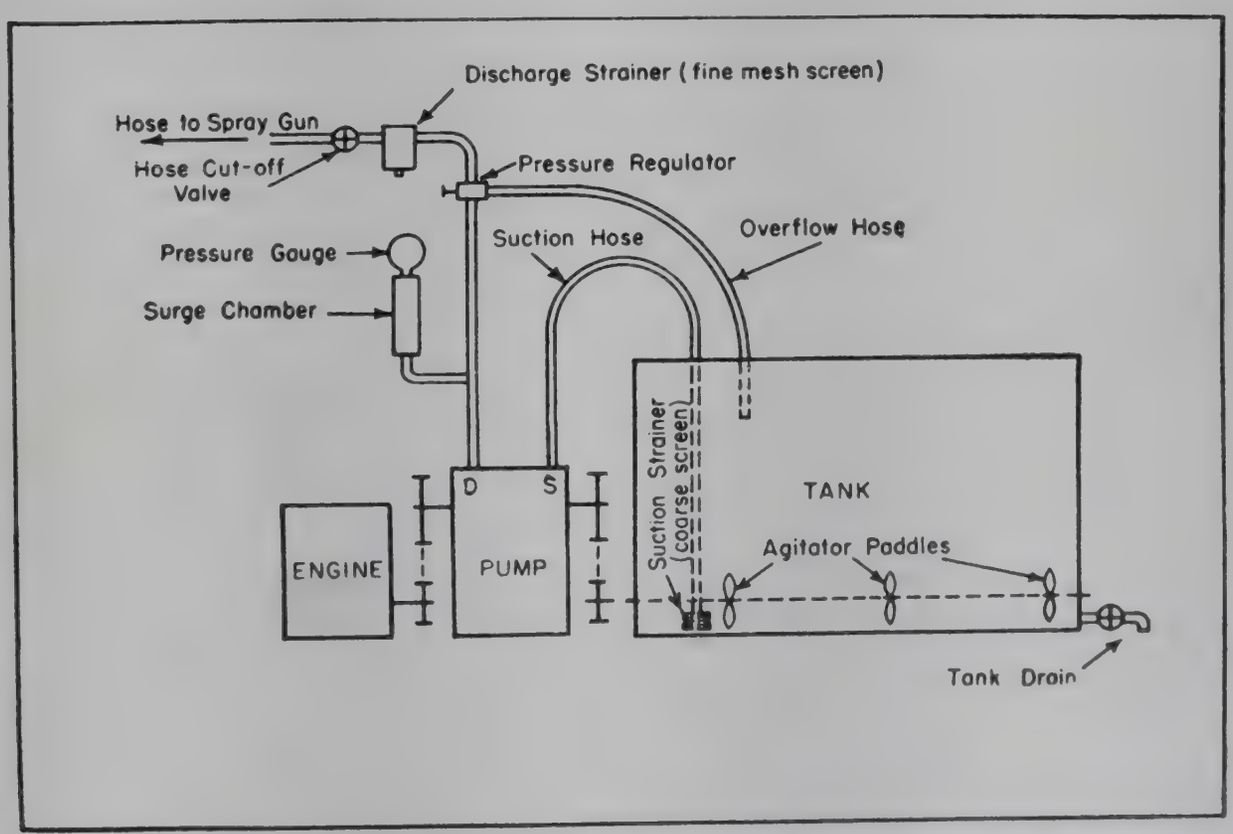


FIGURE 204.—Diagrammatic sketch of power sprayer as modified for residual spraying.

1. The pump, hose, and spray guns should be rinsed with clean water after each day's spraying with DDT emulsions.

2. The pump plungers, pump bearings, agitator shaft, and engine should be lubricated generously.

3. The discharge strainer should be cleaned at least twice a day.

Timber carrier with duckbill hooks, fitted with 2½-inch by 4-foot hickory handle—Dixie Logging Tool Co.'s No. 217, or equal.

Torch, for area or brush burning. To burn kerosene or light fuel oil. Having 4-gal. tank capacity, complete with air pump, 60-pound pressure gage, a 7-foot oil-resisting hose, a special carrying handle for nozzle, and adjustable web shoulder strap—Aeroil No. 99 Senior, Aeriol Burner Co., West New York, N. J. (also 2-gal. and 5-gal. capacity tank as Aeroil Junior and Aeroil Giant respectively), or equal.

Weed cutter (Sythax) with double edge, tool steel, 16-gage blade 11½ inches long and 3½ inches wide, blade weight 1 pound. Weight per tool approximately 4½ pounds. Shank extra heavy with steel channel support for blade. Oval, hardwood handle. Thirty-six inches over-all height—Sythax Co., Memphis, Tenn., or equal.

Weed cutter, underwater machine. Designed and constructed for the purpose of cutting aquatic growth at various depths beneath the water surface to a maximum of approximately 4 feet. The cutting mechanism shall be gasoline power operated, shall be mounted on a pontoon or boat propelled by gasoline power. The assembled machine shall be capable of navigating in water 1 foot deep—C. L. Hackney, or equal.

Inventory of a typical malaria control sub-base

Adz	1	Mattocks	4
Axes, double-bitted	10	Oil can, squirt	4
Bar, pinch	3	Paddle, boat	29
Bits, ½-in., ¾-in.	2	Picks	2
Blades, scythax	25	Pipe cutter	1
Block and tackle	1	Pipe dies, 1¼-in., 1½-in., 2-in.	3
Blowtorch	1	Pitch forks, 6-tine	10
Boots, hip	14	Pitch forks, 4-tine	2
Boots, knee	3	Pliers, 8-in.	8
Brace	1	Pliers, lineman	1
Bucket, water, 12-qt.	1	Pliers, round-nose	6
Bush hooks, double-edge	11	Pumps, pitcher	3
Bush hooks, shop-made	2	Raincoats	6
Bush hooks, single-edge	22	Rakes, garden	2
Cans, gas, 5-gal.	2	Rakes, mower-tooth	2
Cans, gas, safety, 5-gal.	4	Rakes, potato-digger	5
Cans, sprinkler	3	Saws, crosscut	8
Chain hoist	1	Saw, hand	2
Chisels, cold	5	Saw, set crosscut	4
Cushions, boat	7	Screwdriver, 6-in.	5
Cup, oil, measuring, 1-quart	1	Screwdriver, 3-in.	4
Die tap	1	Shovels, long handle, round point	15
Duster, hand	7	Shovels, long handle, square point	1
Fire extinguisher, 2½-gal.	1	Shovels, short handle, square point	2
Fire extinguishers, 1-qt.	10	Sledge hammers, 6-lb.	5
First-aid kits	10	Snips, tin	1
Flashlights, 2-cell	2	Spike poles	3
Flashlights, 3-cell	2	Square, framing	1
Funnel, copper	1	Square, Tri	1
Funnels, tin	8	Tape, steel, 50-ft.	1
Grease guns	2	Timber carriers	3
Hacksaw	1	Tool boxes, small	5
Hammers, ball peen	6	Vise, shop	1
Hammers, claw	2	Whistles, boat, (spare)	1
Irons, soldering	2	Wedge, iron	23
Jugs, thermos, 1-gal.	2	Weed cutters, "Sythax"	7
Kegs, water, 5-gal.	2	Weed cutters, saw tooth, "lively lad"	5
Kegs, water, 3-gal.	2	Wheelbarrow	1
Kegs, water, 1-gal.	2	Wrench, crescent, 12-in.	3
Knapsack sprayers	7	Wrench, crescent, 10-in.	5
Knife, drawing	1	Wrench, crescent, 6-in.	4
Lantern, Coleman	2	Wrench, socket (set)	1
Level, carpenter	1	Wrench, stillson, 36-in.	1
Level, hand	1	Wrench, stillson, 24-in.	1
Life preservers, cork	4	Wrench, stillson, 18-in.	7
Life preservers, Kapok	22	Wrench, stillson, 14-in.	2

APPENDIX E

DESIGN OF AIRPLANE LARVICIDING EQUIPMENT

Airplane dusting equipment

Detailed data for construction and operation of airplane dusting equipment shown in figure 86 are given in the following paragraphs.

Hopper—The hopper should be located near the center of gravity of the airplane to maintain proper weight balance relationships. It should be constructed securely into the structural members of the ship, of smooth, strong and light material such as aluminum or 5-ply wood. The joints must be airtight. Metal hoppers, unless satisfactorily supported, will fail due to vibration. The hopper usually has steep sloping (1 to 1 or greater) sides which direct dust into a throat which extends vertically through the bottom of the fuselage into the discharge venturi. The loading opening should be designed sufficiently large to accommodate either a dust sack or can. The lid should fit tightly with a safe latching device and should be vented to the air. The dimensions of the hopper will be determined by the available space and load limit of the airplane. The volume of the hopper may be computed by dividing the pay load of the ship by the unit weight of the paris green dust after the weights of the hopper, agitator, etc. have been deducted. A small removable hopper for a Stearman PT-17 is shown in figure 205.

Venturi—The dust venturi may have varying shapes. Satisfactory performance may be obtained with rectangle sections having vertical sides. Adequate constriction may be obtained by bolting a sheet aluminum airfoil panel (similar to airplane wing section) into the side walls and fastening it to bottom of fuselage. The bottom of the venturi should have a length to width ratio of 1 to 1. The velocity of air at the point of maximum constriction should be about 300 feet per second. The ratio of section area of the upstream opening to the throat should be 2 to 1; the ratio of the downstream opening to throat should be about 2.7 to 1. The chord of the airfoil section should be horizontal during level flight so that the dust will sweep cleanly along the belly of the ship without undue turbulence.

Agitation—To provide uniform flow of dust into the venturi, mechanical agitation is necessary. This may be accomplished by two open-drum type piano wire agitators placed one above the other in the hopper throat. The lower unit is driven by chain and sprocket from the upper main shaft which is connected to the wind-driven

propeller and right-angled reduction gear by universal joints. The shafts of the agitator should penetrate the hopper, through self-aligning, dust-tight bearings.

The propellers and reduction gear should be designed to drive the agitators at 100 r.p.m. The diameter and pitch of the propeller will depend upon the required power and necessary rpm's.

Propellers may be purchased from aeronautical supply houses on special order or designed and built of spruce or ash by woodworking shops.

General formulae for designing the wind-driven propeller are as follows:

$$\text{Revolutions per minute} = \frac{\text{Air speed of ship in ft. per min.}}{\text{Pitch } (1 + \text{percent slip})}$$

Where pitch $= 6.28 \times$ radius of propeller $\times \tan A$

A is the average angle measured from the chord of the rear face of the propeller to a line at right angles to the propeller shaft.

Percent slip = 15 to 35 percent depending on propeller "bite"

$$\text{Horsepower} = \frac{DSV^3 \times E}{2G \times 550}$$

Where D = weight of air (.081)

$$S = \frac{(\text{Diameter of propeller in feet})^2}{4}$$

V = Cruising air speed of ship ft. per sec.

E = Efficiency 10 to 30 percent (depending on blade design)

G = Acceleration of gravity = 32.2 ft. per sec., per sec.

Figure 206 presents a close-up view of a 4-blade propeller and 50 to 1 reduction right-angled gear box for driving the agitators on a 450 hp. Stearman 4DX Duster. A rectangular sectioned venturi may be seen below the fuselage.

Dust control valve—In order to secure sensitive control on the volume of dust discharged at various valve settings, it is considered essential to provide a thin gauge metal plate on the floor of the hopper just above the valve opening and cut-out to give a parabolic increase in areas of opening for each increasing valve setting. (See fig. 86.) The valve must be sturdy and designed to open and seal freely when the hopper is fully loaded. A simple sliding gate valve supported on either side by channel guides has proved to be satisfactory. The valve can be operated by rigid arms which transmit the force from the valve lever to close the gate into a felt receiving strip. The valve lever, located on the throttle side of the cockpit, is guided against a metal strap drilled for required valve openings made with a removable pin stop.

The entrance of loose dust into the ship must be prevented. All

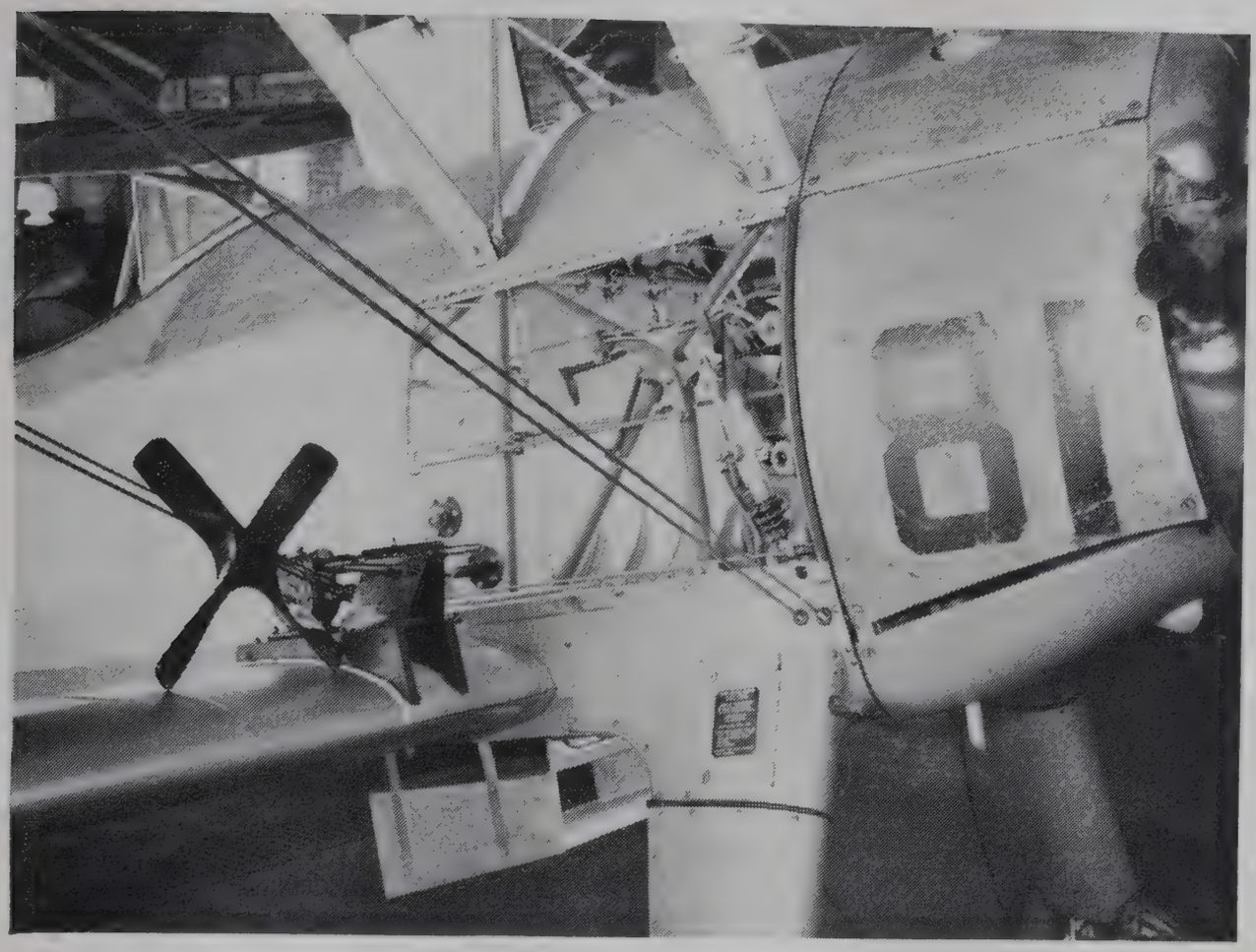


FIGURE 205.—Removable dust hopper in Stearman PT-17 showing agitator and venturi.

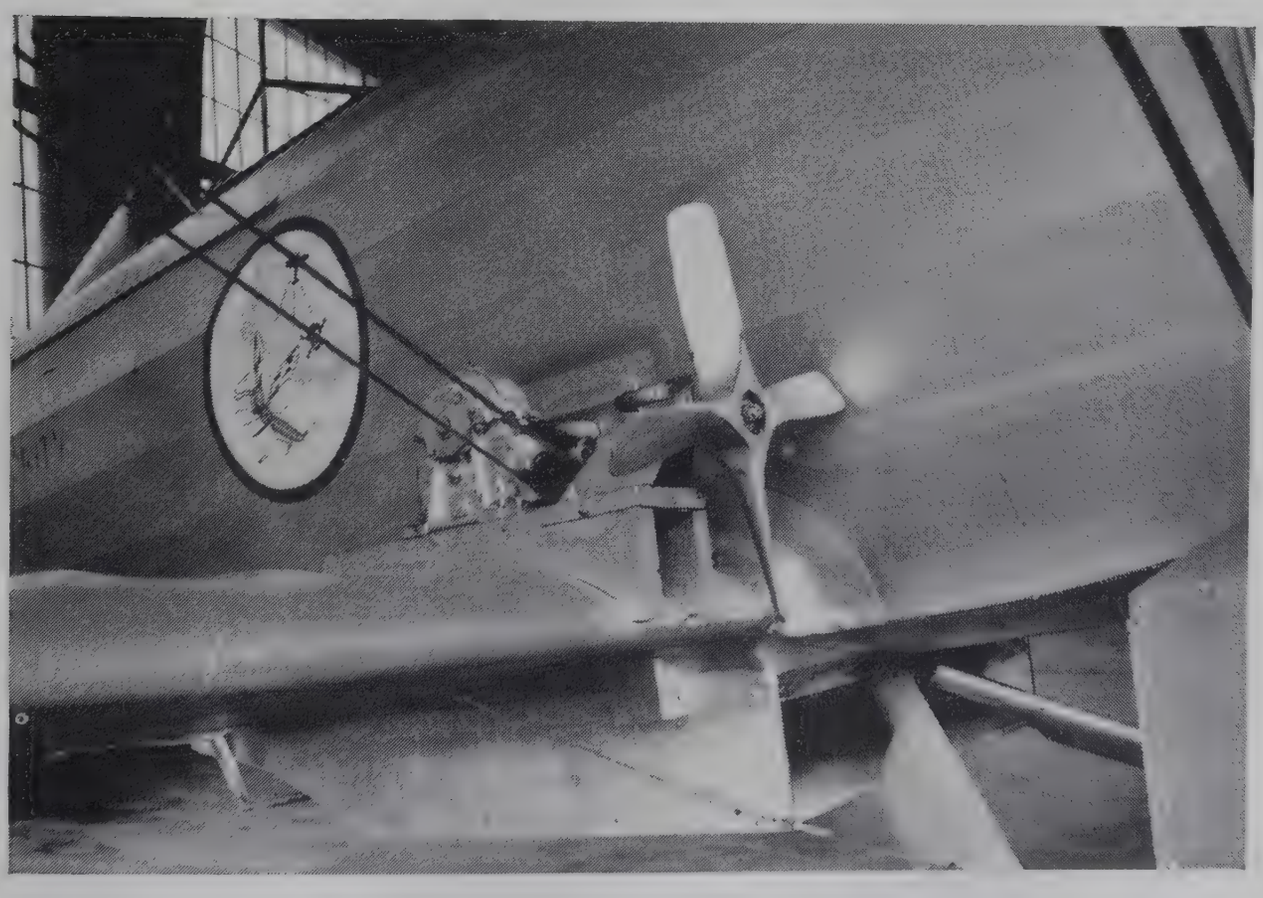


FIGURE 206.—Propeller and reduction gear for agitator with venturi below fuselage.

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control openings about the tail group must be "socked up." It is desirable to install doped linen bulkheads within the fuselage as an added protection against the entrance of dust.

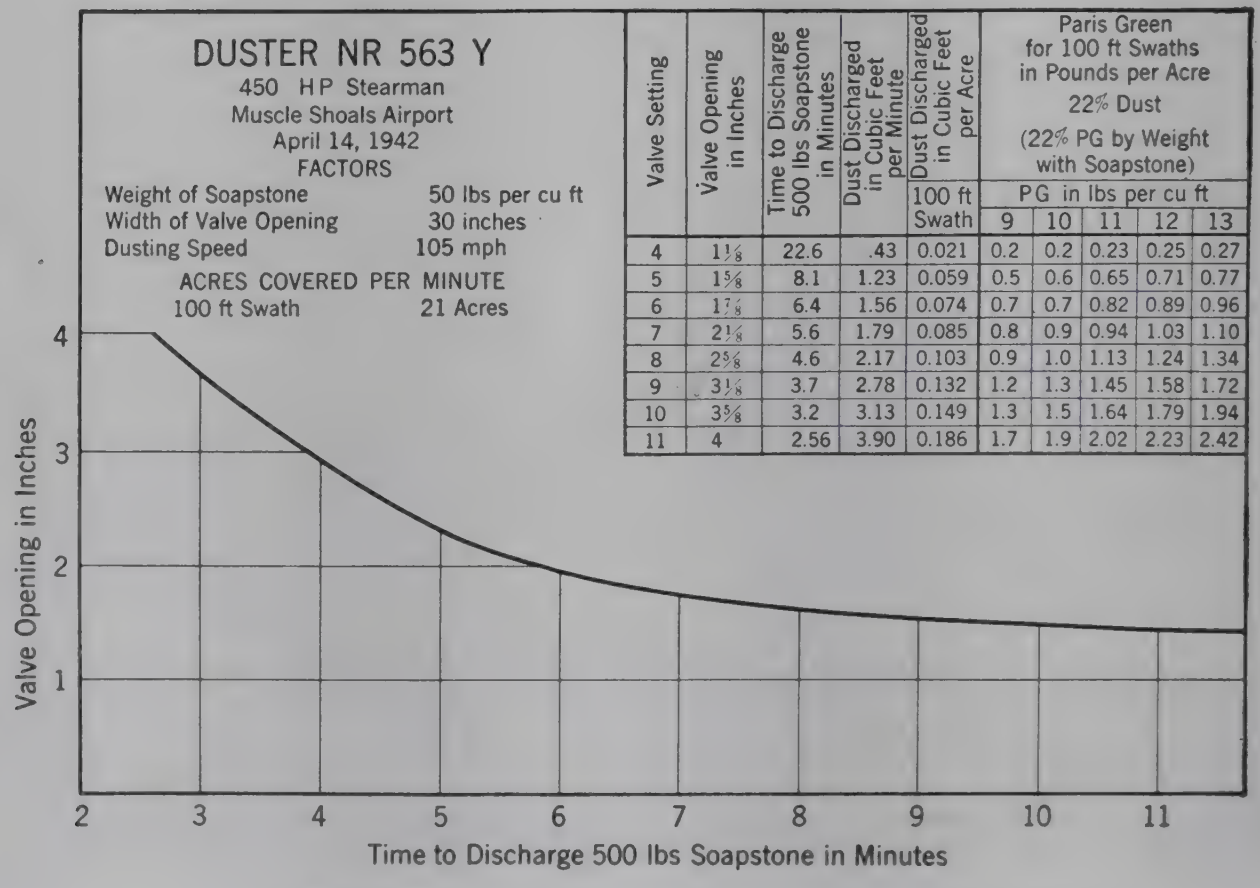
Dust valve calibration—The rate of dust application is expressed in pounds of active larvicide per acre of treatment area. Factors entering into the calibration of dusting airplanes are:

1. Acres per minute treated.
2. Cubic feet of dust discharged per minute.
3. Density of the dusts used.

In practice, treatment swaths are generally assumed to be 100 feet wide; however, airplanes vary in discharge rates and dusting speeds and require separate calibration. The density of dust varies from shipment to shipment regardless of mixtures used and must be considered in the calibration of treatment rates.

A specific valve setting may be calibrated as follows:

1. Determine the amount (cubic feet) of dust discharged per minute using soapstone of known density.
2. Compute acres dusted per minute assuming 100-foot swath width.
3. Cubic feet of dust per acre = (1) divided by (2).


DUSTER NR 563 Y
450 HP Stearman
Muscle Shoals Airport
April 14, 1942
FACTORS
Weight of Soapstone 50 lbs per cu ft
Width of Valve Opening 30 inches
Dusting Speed 105 mph
ACRES COVERED PER MINUTE
100 ft Swath 21 Acres
Valve Opening in Inches
Time to Discharge 500 lbs Soapstone in Minutes

Valve Setting	Valve Opening in Inches	Time to Discharge 500 lbs Soapstone in Minutes	Dust Discharged in Cubic Feet per Minute	Dust Discharged in Cubic Feet per Acre	Paris Green for 100 ft Swaths in Pounds per Acre 22% Dust (22% PG by Weight with Soapstone)				
				100 ft Swath	PG in lbs per cu ft				
					9	10	11	12	13
4	1⅛	22.6	.43	0.021	0.2	0.2	0.23	0.25	0.27
5	1⅝	8.1	1.23	0.059	0.5	0.6	0.65	0.71	0.77
6	1⅞	6.4	1.56	0.074	0.7	0.7	0.82	0.89	0.96
7	2⅛	5.6	1.79	0.085	0.8	0.9	0.94	1.03	1.10
8	2⅝	4.6	2.17	0.103	0.9	1.0	1.13	1.24	1.34
9	3⅛	3.7	2.78	0.132	1.2	1.3	1.45	1.58	1.72
10	3⅝	3.2	3.13	0.149	1.3	1.5	1.64	1.79	1.94
11	4	2.56	3.90	0.186	1.7	1.9	2.02	2.23	2.42

FIGURE 207.—Calibration of dust control valve.

The pounds of active larvicide per cubic foot of mixed dust must be determined and should be tagged on all mixed material. Multiplying the discharge rate per acre for the valve setting times the percent of active larvicide in the dust gives the amount of larvicide applied per acre. A typical calibration curve is shown in figure 207.

Design of venturi for dispersing aerosols

Estimation of volume of exhaust gases from gasoline engines at 1,000° F.—Assumptions:

1. Consumption of fuel at cruising speeds in pounds per hour = 0.288 × maximum rated horsepower.

2. Theoretical equation for combustion of hydrocarbon (gasoline) fuel into the various exhaust components:

$$2\ C_n\ H_{2n+2}+(3n+1)\ 0_2 \rightarrow 2n\ CO_2+(2n+2)\ H_2O$$

Assuming $n=8$ for gasoline, the above formula becomes:

$$2\ C_8H_{18}+25\ O_2 \rightarrow 16\ CO_2+18\ H_2O$$

3. Nitrogen in air = 77 percent
   Oxygen in air = 23 percent

The volume of exhaust gases (carbon dioxide, water, vapor, and unconsumed nitrogen) at 1,000° F. may be computed as shown below.

$$\text{Oxygen required (lbs./hr.)} = \frac{\text{Gasoline (lbs./hr.)} \times 25\ O_2}{2\ C_8H_{18}}$$
$$= 3.51 \times \text{Gasoline (lbs./hr.)}$$

$$\text{Carbon dioxide produced (cu. ft./hr.)} = \frac{\text{Gasoline (lbs./hr.)} \times 16\ CO_2}{2\ C_8H_{18} \times 0.0415}$$
$$= 74.4 \times \text{Gasoline (lbs./hr.)}$$

$$\text{Water vapor produced (cu. ft./hr.)} = \frac{\text{Gasoline (lbs./hr.)} \times 18\ H_2O}{2\ C_8H_{18} \times 0.0165}$$
$$= 86.2 \times \text{Gasoline (lbs./hr.)}$$

$$\text{Nitrogen in exhaust (cu. ft./hr.)} = \frac{\text{Oxygen (lbs./hr.)}}{0.0263} \times \frac{77}{23}$$
$$= 127 \times \text{Oxygen (lbs./hr.)}$$

The sum of the nitrogen, carbon dioxide, and water vapor will give the total volume of exhaust gases in cubic feet per hour.

Notes on venturi design—Since about 90 percent of the static pressure on an engine equipped with an exhaust generator is produced by the head loss through the venturi section, care must be exercised in the design of the venturi. The following design features are essential:

(a.) Included angle of entrance cone 20° to 30°.

(b.) Included angle of exit cone 7°.

(c.) Ratio of throat diameter to pipe diameter 0.25 to 0.50.

(d.) Throat surfaces machined to insure a smooth union with the entrance and exit cone.

(e.) Length of throat section kept to a minimum.

APPENDIX F

METHODS OF DETERMINING THE RECOVERY OF LARVICIDES ON A WATER SURFACE

RECOVERY OF PARIS GREEN

The recovery of paris green on a water surface may be determined by placing petri dishes, 3.5 inches in diameter, on the water surface, and analyzing the dust collected for paris green. The dust is rinsed into a 250 ml. beaker with approximately 125 ml. of 20-percent hydrochloric acid. The resulting solution is then heated to 90° C., three drops of methyl orange indicator added, and the solution titrated until colorless with a standard solution of potassium bromate, made by dissolving 0.1823 grams of $KBrO_3$ in distilled water to make a liter of solution. A 5-ml. microburette should be used for the titration. Correction should be made for the indicator error by titrating blanks of acid plus indicator.

One ml. standard bromate $=\bigcirc=$ 0.32 mg. As_2O_3 $=\bigcirc=$ 0.56 mg. of paris green; therefore, 1 ml. standard bromate $=\bigcirc=$ 0.807 pound of paris green per acre where a 3.5-inch petri dish is used.

RECOVERY OF AEROSOL OR SPRAY DROPLETS ON WATER SURFACE

The recovery of aerosol or spray droplets on a water surface may be determined by allowing the droplets to settle on a clean glass slide at the surface of the treatment area, counting the number of droplets, and measuring their diameter. The apparent diameter of the droplets can be measured with a compound microscope with a calibrated ocular micrometer. For DDT-Velsicol NR-70 solutions, the true spherical diameter of the falling drop is one-third the apparent diameter of the lens shaped drop formed on the glass slide.

By multiplying the weight of DDT in each drop (size) times the number of drops of that size present, and totalling the weight, the amount of DDT present per unit area can be calculated. DDT (pounds per acre) $=$ 0.0178 $\times$ (micrograms of DDT per sq. cm.).

APPENDIX G

THE MORE IMPORTANT ANOPHELES MOSQUITOES TRANSMITTING MALARIA IN THE PRINCIPAL REGIONS OF THE WORLD WITH TYPICAL BREEDING PLACES AND USUALLY APPLICABLE CONTROL MEASURES*

Region	Anopheline mosquito[1]	Habitat and control measures[2] (see key)
1. North America, western	*A. MACULIPENNIS FREEBORNI*	H
2. North America, southern, central	*A. QUADRIMACULATUS*	G
	A. albimanus (Rio Grande Valley)	b
3. Mexico	*A. ALBIMANUS* (coastal)	B
	A. ALBIMANUS	I
	A. pseudopunctipennis (stream bed pools, algae)	d
	A. quadrimaculatus (northeast coastal)	g
4. Central America West Indies	*A. ALBIMANUS*	a B I
	A. aquasalis	a
	A. punctimacula	c
	A. pseudopunctipennis (stream bed pools, algae)	d
	A. darlingi	i
	A. bellator	N
5. South America	*A. ALBITARSUS*	B G
	A. PSEUDOPUNCTIPENNIS (Argentina, Chile, Peru)	D
	A. DARLINGI (north)	l D I
	A. albimanus	b
6. Europe, northern	*A. labranchiae atroparvus*	b
7. Europe, southern	*A. SACHAROVI*	A B
	A. LABRANCHIAE LABRANCHIAE (Portugal, J)	A J
	A. ATROPARVUS (Spain and Portugal)	A
	A. SUPERPICTUS (stony beds)	D F
	A. maculipennis maculipennis (especially Balkans)	d
8. Africa, north	*A. multicolor* (in desert saline water)	a
	A. l. labranchiae	a
	A. pharoensis (Nile delta)	b

Region	Anopheline mosquito[1]	Habitat and control measures[2] (see key)
	A. algeriensis	b
	A. sergenti	d h
9. Africa, central and south	*A. FUNESTUS*	D E
	A. GAMBIAE (west Africa, j)	D H I j k m
	A. funestus	b f
10. Europe, eastern and Russia	*A. SACHAROVI*	A B
	A. MESSEAE	B
	A. M. MACULIPENNIS	B H
	A. SUPERPICTUS	D e
11. Near East and India, extreme northwest	*A. SACHAROVI*	A B
	A. SUPERPICTUS	D E f
	A. pharoensis	b g
	A. sergenti	f h d e
	A. claviger	l
	A. stephensi	l m
12. India, west, north and central	*A. SUNDAICUS* (Bengal)	A
	A. CULICIFACIES	D i
	A. STEPHENSI	L k
	A. philippinensis (Bengal)	g
13. India, northeast, Assam	*A. MINIMUS* (in hill lands, H)	F G H
	A. leucosphyrus	c
14. India, south	*A. CULICIFACIES* (open wells, in sand K)	D K i
	A. FLUVIATILIS (above 2000′ elev. F)	F H
	A. stephensi	l
15. Ceylon	*A. CULICIFACIES* (North Ceylon, k)	D E k
16. Burma, Thailand, Indo China	*A. SUNDAICUS* (also Andaman Islands)	A
	A. LEUCOSPHYRUS	C
	A. MINIMUS	E
	A. ACONITUS	E
	A. barbirostris	b
	A. annularis	b j
	A. tesselatus	b
	A. culicifacies	d k

Region	Anopheline mosquito[1]	Habitat and control measures[2] (see key)
	A. jeyporiensis (?)	d e
	A. maculatus	f
	A. philippinensis	g
	A. hyrcanus	j
17. China	*A. MINIMUS* (South China)	E
	A. tesselatus	b
	A. jeyporiensis (?)	d
	A. maculatus	f
	A. pattoni	j
	A. hyrcanus	j
18. Malaya	*A. SUNDAICUS*	A
	A. UMBROSUS	C K
	A. MACULATUS	F
	A. barbirostris	b
	A. aconitus	j
19. Netherlands East Indies	*A. SUNDAICUS* (also in fish ponds)	A
	A. UMBROSUS	C
	A. LEUCOSPHYRUS (in Borneo)	C
	A. aconitus	e
	A. maculatus	f
	A. subpictus	i
	A. hyrcanus (also in fish ponds)	j
20. Philippine Islands	*A. MINIMUS FLAVIROSTRIS*	F
	A. mangyanus	f
21. South Pacific Islands	*A. PUNCTULATUS MOLUCCENSIS*	A B D E F I m
	A. PUNCTULATUS	B I
22. Australia	*A. PUNCTULATUS*	B I
	A. punctulatus moluccensis (?)	

[1] Species in capitals are primary vectors of the first importance over large areas in the indicated region. Species in small letters are either vectors in small localized areas only, or are secondary vectors in epidemics initiated by primary vector species. *Anopheles* species whose normal vector efficiency is doubtful have been omitted.

[2] Letters refer to habitats and control measures listed in the following key. Principal breeding places are indicated by capital letters and less important habitats by small letters.

A few *Anopheles* species breed in epiphytes (air plants on trees). *A. bellator*, for example, is the vector in Trinidad. *A. darlingi* sometimes breeds in bromeliads.

Japan has little malaria. The vectors are probably *A. pattoni* and *A. hyrcanus*.

KEY

Symbol Typical breeding places	Control measures usually applicable
A—Brackish water and coastal marshes, usually open to sunlight.	Increase salt content of water by flooding with sea water, or decrease salt content by flooding with fresh water. Natural or artificial fill. Open marsh ditching. Diking and dewatering, tide gates and drains. Oiling. Paris green. DDT.
B—Fresh-water swamps and weed-grown waters, usually open to sunlight.	Drainage. Natural or artificial fill. Enclosure by dikes, with constant level flooding plus larvicidal fish. Pollution and packing with decaying vegetation. Larvicidal fish. Shading. Paris green. Oiling. Pyrethrum larvicide. DDT.
C—Fresh-water swamps, pools, stream beds, etc., under forest, jungle or dense shade.	Drainage. Natural or artificial fill. Clearing to let in sunlight. Pollution and packing with decaying vegetation. Paris green. Oiling. Pyrethrum larvicide. Larvicidal fish. DDT.
D—Large rivers with their associated pools and seepages.	Channelizing stream bed. Controlled silting of stream bed sides. Clear away or poison grass. Larvicidal fish. Paris green. Oiling. Pyrethrum larvicides. Large scale flushing in some cases. DDT.
E—Irrigation channels, ditches, and small sluggish streams.	Channel lining. Keep sides and bottom clear of vegetation and obstructions. Bank training. Flushing. Dense shading. Larvicidal fish. Oiling. Pyrethrum larvicide. Paris green. DDT.
F—Hill and mountain streams, with associated pools and seepages.	Flushing, automatic or hand operated. Shading. Channelizing stream bed. Larvicidal fish. Continuous drip oiling. Oiling. Paris green. Pyrethrum larvicide. DDT.
G—Margins and shallows of reservoirs, ponds, lakes, lagoons, and bayous.	Clear reservoir of all vegetation before filling. Clear vegetation and flotage from banks. Fluctuating water levels. Larvicidal fish. Apply paris green or oil by airplane or from boats. Copper sulphate to minimize algae. DDT. Drainage.
H—Shallow seepages from irrigation, springs, overflows, etc., usually in sunlight.	Restriction of excessive use of irrigation water. Canal or ditch lining, or piping, to reduce seepage. Pump out low areas and return water to irrigation canal or drain. Drainage, open, sub-soil, or vertical. Larvicidal fish. Paris green. Pyrethrum larvicide. Oiling. DDT.
I—Rain water pools in borrow pits, excavations, wheel ruts, wallows, etc.	Open drainage. Sub-soil drainage. Vertical drainage. Filling. Pollution and packing with decaying vegetation. Oiling. Pyrethrum larvicides. Paris green. Cresylic acid larvicide. DDT.
J—Rice fields.....	Carefully level paddies before planting. Keep banks free from vegetation. Usually shade ditches and drains. Larvicidal fish. Intermittent drying of paddies. Muddying water. Pyrethrum larvicide. Paris green. Oiled sawdust. DDT.
K—Wells.....	Mosquito-proof covering or screens. Fill abandoned wells. Pyrethrum sprays. Kerosene. Open, shallow wells may be treated as pools. DDT.
L—Cisterns, covered water storage tanks, etc.	Mosquito-proof covering or screens. Frequent change of water, with surface disturbance. Larvicidal fish. Pyrethrum sprays. Kerosene. DDT.
M—Artificial containers—barrels and barrel heads, buckets, cans, gourds, boats, cocoanut shells, etc.	Empty, remove, puncture or destroy all useless containers, cans, shells gourds, etc. Stand oil drums on sides. Empty water out of boats Cresylic acid larvicide. Phenothiazine. Borax. Oiling. DDT.
N—Bromeliads in trees.....	Kill plants with copper sulfate spray. Cut off plants.

* Adapted from: Herms, W. B., and Gray, H. *Mosquito Control*, Second Edition. Commonwealth Fund, New York.

APPENDIX H

MALARIA SURVEY DIAGNOSTIC TECHNIQUES

BLOOD FILMS

Blood for making films is most conveniently obtained by puncturing the tip of one of the fingers. In the case of infants, the great toe or the heel may be used. Drawing blood from the lobe of the ear once had many advocates and is still used occasionally under special circumstances. Whatever part of the body is selected, the site of the puncture is first cleaned with alcohol or some other volatile solvent in order to remove dirt and grease from the site and to sterilize it (fig. 208). The site is then wiped dry with a bit of gauze or cotton for the reason that the cleaning fluid used would "fix" the blood, preventing proper staining. The skin is then punctured with a sharp instrument to a depth sufficient to produce a freely flowing drop of blood (fig. 209). This may be done with a triangular needle (Hagedorn type) or a Bard-Parker No. 11 knife blade driven through a cork with the unprotected portion just long enough to produce the desired depth of puncture. The cork with the protruding instrument may be kept in a bottle of 80-percent ethyl alcohol for sterilization purposes. Spring lancets were formerly advocated, but they tend to produce more pain and their use has some inherently dangerous features.

When the thick film is to be made, a 1 by 3-inch glass slide, chemically clean and free from dust, is lowered gently (fig. 210) until it comes in contact with the drop of blood, which adheres to it by surface tension (fig. 211). The slide may then be removed quickly and the operation repeated until five small drops of blood are collected at one end of the slide (fig. 212). Subsequently these drops are joined with the corner of another slide until a single drop the size and shape of a 5-cent piece, or slightly smaller, has been made. If this method is used, care should be taken not to agitate the blood more than is necessary in order to prevent the formation of clumps of fibrin. An alternative method is to keep the end of the slide in contact with the drop of blood (fig. 213) and move the slide gently in a circular direction until a drop of the size required has been obtained. In both methods care must be taken that the surface of the slide does not come in contact with the finger; otherwise, oily material may be taken up with the blood and cause the thick film to flake off. The

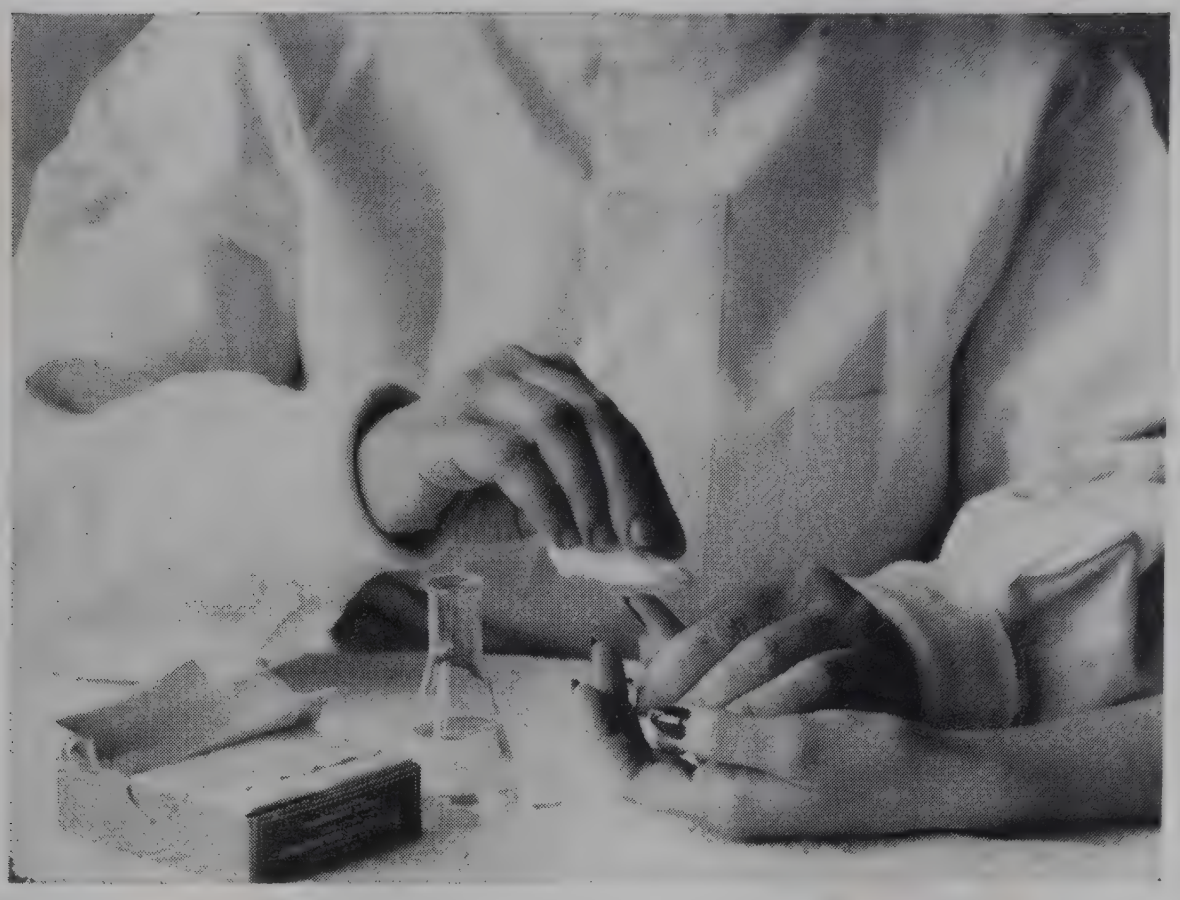


FIGURE 208.—Cleansing the finger with alcohol.

FIGURE 209.—Puncture of finger. (Note the welling drop of blood.)

FIGURE 210.—Lowering the slide to the drop of blood. (Note the slide being held only by the edges.)

FIGURE 211.—Touching the drop of blood with the slide. (Note the slide does not touch the finger.)

FIGURE 212.—Appearance of blood drops before they are joined to make a thick film.

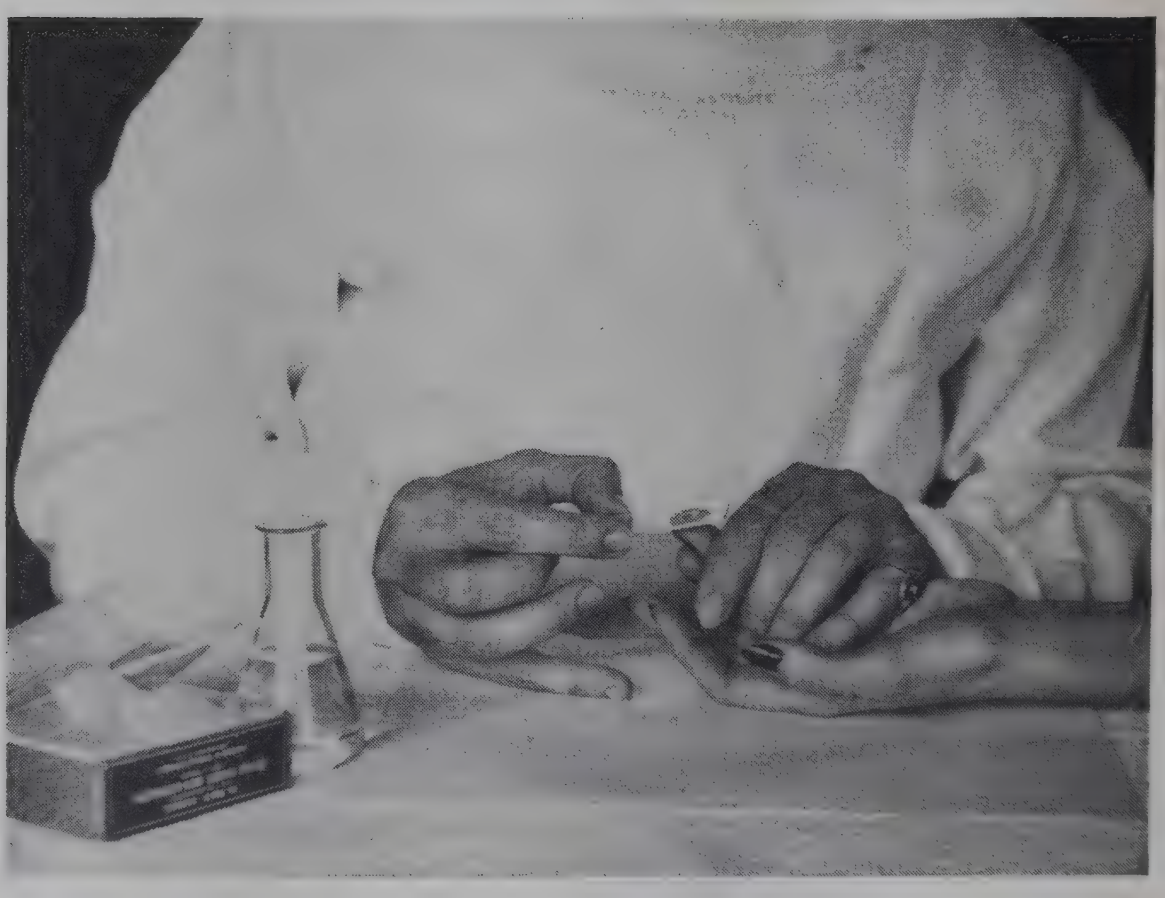
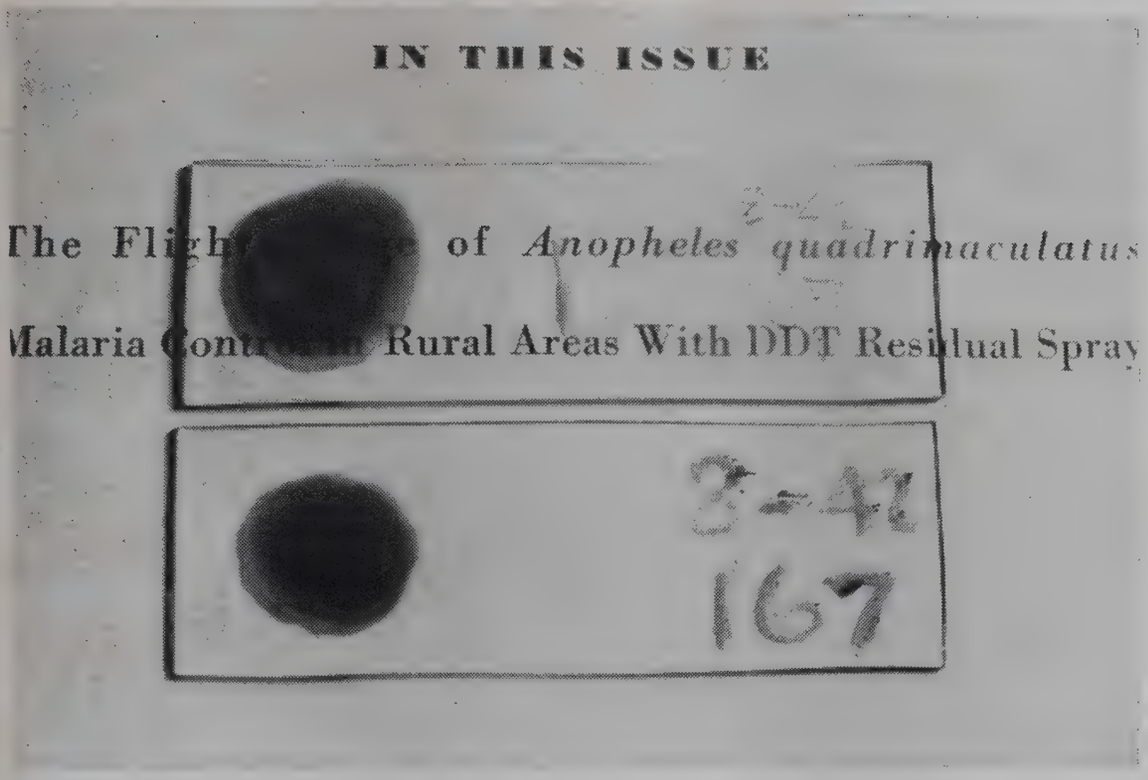


FIGURE 213.—A thick film can be made without removing the slide from the blood coming from the finger wound.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The Fli[redacted] of *Anopheles quadrimaculatus*

Malaria Cont[redacted] Rural Areas With DDT Residual Spray

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FIGURE 214.—Properly made and identified blood films.

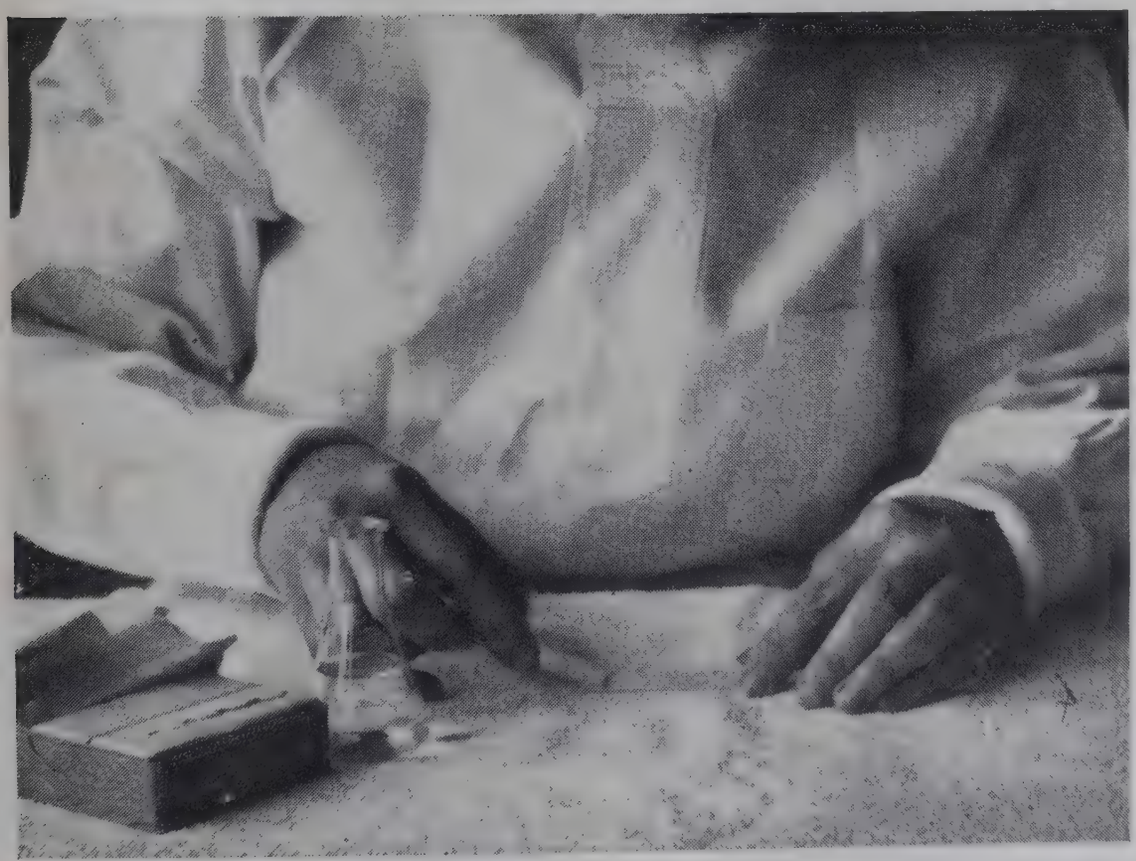

FIGURE 215.—Technique for preparing a thin film. (Note the angle of the slide making the film.)

thick film, when wet, should just permit newspaper print to be read through it (fig. 214).

When a thin film is to be made, a single drop of blood is obtained at one end of the slide (at the end opposite the thick drop when both films were taken on the same slide). The slide is then placed on a flat surface and the edge of the end of another slide of the same size is brought in contact with the drop of blood and the first slide (fig. 215). The blood will spread along the point of contact by surface tension. With the second slide held at an angle of about 30 degrees, the drop is spread by pulling it by surface tension. A properly made thin film will dry almost at once if the humidity is not too high. The film should have a uniform thickness of one layer of red cells. Ideally, a thin film under the microscope will have the appearance of a honeycomb, the blood cells just touching each other.

Thick and thin films may be taken on the same slide, in which case the thin film should be made first. Such slides can be identified by writing some identifying symbol with a hard lead pencil in the thickest part of the thin film (fig. 214). When thick films only are made, this identifying symbol may be affixed to the slide with a wax pencil and should be placed at the end opposite the thick film. In the field, special precautions must be taken to keep the slides level and away from flies and dust until the slides are thoroughly dry.

SPLEEN EXAMINATIONS

The presence and size of an enlarged spleen can best be determined by having the person examined lie upon his back with the knees drawn up and the hands placed along the sides. Standing on the right side, the examiner with his right hand gently feels the left side of the abdomen to determine whether a grossly enlarged spleen is present. If none is felt, the examining fingers are gently pushed up beneath the ribs in the left flank, and the person being examined is requested to breathe deeply. The spleen is pushed down on deep inspiration, and the smallest enlarged spleen can frequently be felt in this way. For purposes of weighting, nonpalpable spleens may be given a value of 0; those felt only on deep inspiration (PDI), 1; those felt at the margin of the ribs on normal inspiration (size 1), 2; those extending half way to the umbilicus (size 2), 3; those extending beyond this point but not beyond the umbilicus (size 3) , 4; and those extending beyond the umbilicus (size 4), 5.

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